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DEVELOPMENT OF A TEST PROGRAM TO EVALUATE STRUCTURAL DEFECTS IN GLASS-REINFORCED PLASTIC (GRP)

Volume I

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16. Abstract

A mechanical testing program was developed for evaluation of the weakening effects of different types of commonly encountered flaws on the strength of composite boat hulls. A specification was developed for production of test coupons containing realistic and consistently reproducible simulated defects. Tensile and flexural testing procedures were specified, including development of a technique for tensile testing of cored specimens. A statistically-based test plan was developed.

A mechanical testing program was conducted in which approximately 400 specimens were subjected to either tensile or flexural testing. this program was conducted to verify specimen production techniques, to validate mechanical testing procedures, and to acquire information about the statistical variability of test results, which is necessary for planning future experiments.

The data from the testing also supported a limited number of conclusions about the effects of defects on the strength of composite specimens of solid, balsa-cored, and plastic foam-cored construction.

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METRIC CONVERSION FACTORS

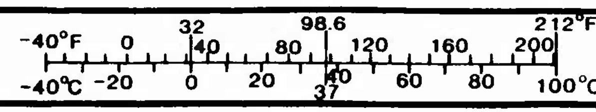
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



CONTENTS

LIST OF FIGURES

LIST OF TABLES

VOLUME II

ENCLOSURES

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Abstract

A mechanical testing program was developed for evaluation of the weakening effects of a number of different types of commonly encountered flaws on the strength of solid and cored composite boat hulls. Techniques were specified for the production of contact-laminated, room-temperature cured glass-reinforced polyester test coupons having consistent properties. The laminates involved were a solid layup approximately 1/2" thick, and cored laminates having balsa core and two types of plastic foam cores, approximately 5/8" thick. Coupons measuring 4" x 24" are to be cut from larger panels, approximately 3' x 6'. Procedures were developed and specified for the introduction of 9 different types of simulated defects into the test coupons, so that those defects would have realistic and consistently reproducible effects and accurately controlled sizes. Defect types included voids, uncured resin, dry fibers, delaminations, simulated cracks, impact damage, excess core filling, lapped reinforcement, and dirt inclusions. A technique was developed for reinforcing cored coupons to allow tensile testing. Tensile and Flexural testing procedures were developed and the necessary equipment was identified and specified. A test plan, based upon statistical principles, was developed to ensure that conclusions based upon test results would be statistically supportable.

A small pilot testing program was conducted in which approximately 400 specimens were subjected to either tensile or flexural testing. This program was conducted to verify specimen production techniques, to validate mechanical testing procedures, to evaluate the legitimacy of extrapolating panel properties from specimen test results, and to acquire information about the statistical variability of test results, which is necessary for planning future experiments.

One phase of the pilot testing program, involving flexural testing of coupons of various widths, was designed to identify the maximum flaw size which could be introduced into the relatively narrow (4" wide) test coupons without significant interaction between the defects and the free edges. Results of this phase were inconclusive.

A second phase involved the flexural and tensile testing of groups of 4" wide coupons, with each group containing unflawed coupons and coupons having two flaw sizes. Several of the individual experiments in this phase yielded statistically supportable conclusions about the weakening effects of defects.

The pilot testing program also yielded valuable information about the statistical variability which can be expected in the results of tests of this type, information which is necessary in the design of more conclusive large-scale experiments. The results showed fairly low variability (standard deviations of about 5% of total strength) between unflawed coupons from the same panel. Significant variability was found between the average strengths of unflawed specimens from different panels.

Preface to Volume I

This Report, titled "Development of a Test Progrmam to Evaluate Structural Defects in Glass-Reinforced Plastic (GRP)" consists of two volumes. This volume, Volume I, contains the main body of the report and appendices relating to the production of test coupons for the pilot testing program and results and analysis of the pilot testing program. Volume II contains the three principal working documents developed during the project, the Test Coupon Production Specification, the Test Procedure, and the Test Plan.

1 INTRODUCTION

The purpose of this project was to develop a program for evaluating the structural effects of defects in solid and cored glass reinforced polyester boat hulls. The Coast Guard expects an increase in both the number and the size of the composite-hulled vessels for which it has inspection responsibilities. To date, there is a lack of information about nondestructive evaluation techniques for composite vessel hulls, and there is little guidance for inspectors in interpreting the results of structural inspections on composite structures.

Prior and concurrent projects have investigated and are investigating various nondestructive test techniques for identifying and classifying defects. This project is the first step in an effort to determine the structural effects of various commonly encountered types of defects which can be detected and identified by emerging nondestructive evaluation techniques. The eventual goal is to establish the relationships between the defect size and the degree of structural degradation due to the defect. Of particular importance is the identification of a minimum critical defect size for each type of defect; this information establishes the required level of performance for the nondestructive identification techniques.

The project included specifications for the fabrication of test specimens which have carefully controlled defects built into them, a standardized procedure for mechanical testing (tensile and flexural), and a test plan to insure that statistically significant data would be obtained from the testing.

The initial phase of the nondestructive test method evaluation (Bar-Cohen 1990) was completed before the beginning of this project. Other work relating to defect identification was in progress at the time of this report.

2 SUMMARY OF THE PROJECT

The project comprised seven major phases:

1. Development work culminating in detailed specifications for the fabrication of test specimens. The Test Coupon Production Specification (TCPS), (Enclosure 1 of this Report, contained in Volume II), is the product of this first phase. This included the development of standardized techniques for producing consistent simulated defects in test coupons.

2. The development of laboratory procedures for tensile and flexural testing of specimens produced according to the production specification developed in phase 1. The Test Procedure (Enclosure 2 of this Report, contained in Volume II) is the product of this second phase.

3. The development of a comprehensive statistically based Test Plan for further full-scale testing. The Test Plan (Enclosure 3 of this Report, contained in Volume II) is the product of this phase.

4. Formulation of a pilot test program to support the development of the TCPS and the Test Procedure and to accumulate an initial set of mechanical testing data and related statistics to be used in the development of a comprehensive Test Plan.

5. A Coupon fabrication program to produce test specimens for the pilot test program. The specimens produced included 4 core types and 9 defect types for both tensile and flexural testing.

6. The testing of the specimens for the pilot test program.

7. Analysis and evaluation of the results of the pilot test program.

3 DEVELOPMENT OF THE TEST COUPON PRODUCTION SPECIFICATION

The Test Coupon Production Specification (TCPS), (Enclosure 1 of Volume II of this Report), was developed for the production of rectangular test specimens, however, most of the specification is applicable to specimens of any size and shape, should changes in coupon configuration be deemed advisable for a full-scale testing program.

3.1 Test Specimen Configuration

The testing program is based upon tensile and flexural testing of rectangular specimens cut from simulated hull panels of realistic thickness and layup type. In order to accommodate defects as large as possible compared to the thickness of the laminate, large specimens are required. Based upon testing machine limitations, a standard specimen size of 24" long by 3.875" wide was selected for both the pilot testing program and as a primary specification for a future full-scale test program.

3.2 Defect Production Techniques

Four hull construction types were simulated: a solid glass/polyester layup approximately 0.5" thick and three cored layups (sandwich constructions) using two types of plastic foam core materials and balsa-core, each approximately 0.63" thick with 1/2" thick cores. Suitable specimens were required for two types of tests, a tensile test similar to ASTM D-3039 and a flexural test similar to ASTM D-790. Specimens for each layup type/test type combination were to include unflawed coupons as well as coupons containing the following simulated defects and nonuniformities:

1. Large-Scale Voids
2. Internal Uncured Resin Inclusions
3. Resin-Starved Areas (dry fibers)
4. Interlaminar Separations (internal delaminations)
5. Cracked Skins (broken reinforcement)
6. Impact Damage to One Face
7. Excess Core Filling (for cored constructions only)
8. Lapped Reinforcement
9. Internal Foreign Material Inclusions

A number of potential techniques for producing each kind of defect were tested. In each case, a technique was selected that would produce defects which had the most realistic effect on mechanical properties and which could be accurately and consistently reproduced by a reasonably proficient fiberglass worker.

Approximately one hundred small sections of both cored and solid laminate, each containing a defect produced by one of the potential techniques, were produced during the development of the defect production methods. These were cut apart, inspected, and evaluated. The various techniques were judged by several criteria:

- Realism. How well the technique simulated the actual defect. The structural effect, rather than the appearance of the defect, was the primary criterion here. Displacement and/or interruption of the fiber reinforcement are the primary effects of the various defects on the laminate structure. The defect production techniques were designed to reproduce these effects.

- Reproducibility and accuracy of positioning. Whether the technique consistently produced defects which had the same physical characteristics and the required dimensions, and whether the same technique, in the hands of various technicians, would produce similar results. Accurate positioning of the defects in the panel was important and techniques which facilitated accurate positioning were favored. Techniques for which high levels of skill or excessive amounts of practice were necessary in order to produce consistent defects were avoided where possible in favor of simpler methods.

- Verifiability. Whether the defect type, size, and position could be visually identified in a finished laminate. Certain of the defect production techniques specified in the TCPS include means of marking the defect so that it is visible through the surface layers of the laminate.

This initial experimentation led to detailed specifications of defect production techniques which were employed in the production of specimens for the pilot testing program. With a few minor changes resulting from experience gained during the pilot program, these techniques are specified for the production of test specimens for a full-scale testing program.

3.3 Panel Layup Techniques

The individual test coupons are cut from larger panels. The size of the panels fabricated for the pilot testing program and subsequently specified for production during a full-scale program was determined by several requirements:

- The specified panel size must be large enough to allow all of the coupons for a given experiment to be cut from the same panel. An experiment is defined as a group of tests on specimens having the same defect and core type, and for the same test type (flexural or tensile). As a general rule, the only variable in a given experiment is defect size. An exception to this rule is the sensitivity study for identifying edge effects which was part of the pilot test program. In this case, both specimen width and defect size were varied.

- The panels must be small enough to be produced by one person or at least by a small team under the direct supervision of one person. This is essential in maintaining consistency in the physical properties of the laminate. These properties, which include the resin/glass ratio and the void content, tend to be more or less constant for a given worker but may vary significantly from one worker to another.

An important part of the production specification is the requirement that each panel be fabricated in one continuous process. This insures that primary chemical bonding occurs between each layer, which is an important factor in producing test specimens. The one-step layup is standard practice in test coupon fabrication, and is easily accomplished for standard ASTM test coupons, which are generally quite small and thin. Real boat hulls, however, especially thick ones, are often laid up in two or more stages, with the later stages laid up over fully cured earlier stages. This multi-stage process prevents full chemical bonding between stages, resulting instead in a secondary adhesive bond. The soundness of this secondary bond varies with the quality of the preparation of the already-cured surface before additional laminate layers are added.

Because the a secondary bond layer in a test specimen could mask the effects of intentionally introduced defects, it is important that there be no secondary bonds in test specimens.

For the full-thickness simulated hull sections required by this project, (especially for the 1/2" thick solid layup, which contains 21 individual layers of reinforcing material) certain precautions are necessary to guard against excessive heat buildup during continuous panel layup. The high density and rather high exothermic heat production of the fire-retardant resin used throughout the project compounds the problem. The necessary precautions include control over the initial temperatures of the materials, over the temperature in the layup area, and variations in the time between placement of individual layers.

Aside from the defect production techniques, the overall methods of coupon production were designed carefully in order to eliminate to the greatest extent possible any factors which might cause local variations in the mechanical properties of the laminate, and which might obscure the effects of the defects on those mechanical properties.

Even though few direct comparisons of properties are expected to be made between specimens originating in different laminate panels, every effort has been made to specify panel layup and curing techniques that minimize variations in the basic properties of the laminate between panels manufactured at different times.

3.4 Technical Discussion

3.4.1 Coupon Size Determination

Several factors affected the selection of an appropriate test coupon size. Zweben et al (1979) point out that composites are actual heterogeneous materials which are conveniently treated, for testing purposes, as anisotropic homogeneous materials. In order for this assumption to be valid the dimensions of the specimen must be large with respect to any characteristic dimensions of the heterogeneity such as layer thickness or fiber yarn widths. The structure of the primary reinforcing material in the solid layup, which is 0/90° 24 oz. woven roving, has a characteristic size on the order of .25 in. The other primary reinforcing materials, 0/90° 10 oz. cloth and ±45° DBM-1708 unwoven roving/mat have characteristic dimensions somewhat smaller than those of the woven roving. In order to minimize effects due to such heterogeneities, a coupon width at least an order of magnitude greater than the heterogeneities was desired.

Practical considerations required that testing be done on full-sized laminate sections. Model testing is a possibly in many areas of engineering, but for a heterogeneous material, it requires scaling down not only of the dimensions of the specimen, but of the internal components as well. Scaled-down reinforcing fabrics are simply not available, and even if they were, the impossibility of scaling down the individual fiber diameter might render the modelling invalid.

Test coupons have a different state of stress than equally wide strips of wide panels due to the presence of the free edge. Several researchers point out that the area affected by the free edge is approximately as wide as the specimen thickness for laminates composed of 0/90° reinforcement material. (Whether that thickness should include the core thickness for specimens of sandwich construction is not clear.) The existence of edge effects makes large specimen width/thickness ratios desirable.

Further, since defects are to be introduced into test specimens, and since many of the defect types studied typically have sizes substantially greater than the hull thickness, the largest possible specimen width is required to enable the largest possible defects to be tested. Defect size is further limited by the possibility that interactions between stress concentrations around the defects and the unrealistic stress patterns near the free edge might render test results inconclusive when the defect size approaches a significant fraction of the specimen width.

Testing machine limitations placed a 3-7/8" width limit on specimens, and considering the reasons cited above for using the widest possible specimens, this measurement was adopted as the standard specimen width.

3.4.2 Reinforcement Orientation

All testing was done on coupons which were cut from panels in such a way that the longitudinal axis of the coupon was aligned with the warp direction of the reinforcing fabric. In vessels built inside female molds the reinforcement fabric is generally laid transversely in the mold. Therefore, the longitudinal axis of the test specimens most closely represents the transverse direction of an actual hull panel. Since all the reinforcement materials used have more or less equal amounts of reinforcement in the warp and fill directions, the orientation of the coupons with respect to the fiber warp is not expected to be a highly significant factor affecting the interpretation of test results.

For cored coupons the predominant reinforcement is the DBM-1708 biaxial mat/roving, the roving component of which is aligned in the $\pm 45°$ directions with respect to the coupon axis. Thus, in tension or flexure, cored coupons act primarily as angle-ply laminates.

For solid coupons, the predominant reinforcement is the 8 layers of 24 oz. woven roving in the core, the fibers of which are aligned in the 0/90° directions. In tension, the solid coupons are primarily 0/90 laminates; however, in flexure, the DBM-1708 layers, being near the surface and thus more highly stressed than the inner roving layers, are expected to be more important, resulting in a laminate with a combination of 0/90° and angle ply properties. Whitney (1973) points out that the properties of angle-ply coupons are highly matrix-dependent and are also width-dependent, while the properties of 0/90° laminates are more or less fiber-dependent and are fairly independent of coupon width. (These observations concern coupons without large flaws - the properties of grossly flawed specimens like those tested in this project might be width dependent even if unflawed specimens of the same type do not show significant width dependence.)

3.4.3 Defect Size Limitations

Many of the defects studied (Delamination, Dry Fibers, and Uncured Resin inclusions in particular) can and do occur in actual boats in sizes which are large in relation to the hull thickness. In these experiments, the ratio of defect size to coupon thickness is limited by the coupon width and possibly even more severely by interactions and stress concentration effects due to proximity of defects to the edges of the coupon. For certain defects, the smallest defect size/hull thickness ratio that results in a significant loss in strength may be much larger than the largest defect size/coupon thickness ratio which can be achieved in coupon testing. While the results of a coupon experiment might verify that the largest defect which can be incorporated into a test coupon does not cause any significant degradation in strength, it might not be possible to determine the defect size which does cause significant weakening.

4 DEVELOPMENT OF THE TEST PROCEDURE

The Test Procedure, (Enclosure 2 of Volume II of this Report), was developed to specify a consistent and workable procedure for tensile and flexural testing of solid and cored rectangular glass/polyester test specimens.

One of the initial constraints placed on the program was the requirement that testing be limited to rectangular coupons with their long axes aligned with the warp direction of the principal reinforcement layers. Testing machine constraints limited the widths of these specimens to a maximum of 3.875".

Development of the Test Procedure included preliminary testing of a number of specimens similar to those used in the main part of the pilot testing program. These specimens were used as practice specimens to develop specific aspects of the testing and coupon production procedures, such as experimentation with core fillers for tensile testing of cored specimens, evaluation of various load spans for flexural testing, etc. Appendix A tabulates the results of testing these preliminary specimens and indicates various decisions made as a result of these tests.

4.1 Tensile Testing

After preliminary testing with several end tab configurations and with untabbed specimens, it was decided that there was no advantage to the use of external end tabs, either on solid or cored specimens. While end tabs are essential to proper transverse distribution of tensile loads in unidirectionally reinforced solid coupons, this function is adequately carried out by the internal 90° and ±45° reinforcements in the coupons used in this program. The grip area of the tensile testing machine used for the pilot test program spanned 3.5" of the 3.875" coupon width.

Tensile testing of cored test coupons presents unique problems. Because of the limited compressive strength of the core materials across the specimen thickness, it is impossible to grip a cored specimen in a tensile testing machine without crushing the core and deforming or breaking the skin. Accordingly, the core under the grip region must be replaced by a harder material.

Preliminary tests were conducted with unreinforced cores of the three types used, and with core reinforcements of flat-grain plywood, polycarbonate, and acrylic sheet. It was found that neither unreinforced plastic foam cores nor plywood reinforced foam cores could resist the compressive forces generated in the tensile machine grips, and that the subsequent crushing caused premature failures near the grips.

For the particular layup used in these tests, it was found that specimens with end-grain balsa cores could be tested satisfactorily without core reinforcement if great care was taken to avoid grip pressures beyond the minimum required. However, calculations show that the end-grain compressive strength of balsa is very close to the pressure generated in the grips. The use of grip pressures only slightly greater than the minimum required to avoid grip slippage could result in core crushing, which could lead to premature failure of the specimen at the grips. Consequently, the same core reinforcement was specified for balsa-cored specimens as for plastic foam-cored specimens.

Both Acrylic and polycarbonate sheet of the same thickness as the core material were found to be fully satisfactory materials; acrylic was specified for further use since it is less costly than polycarbonate and because the adhesive bonding between polyester resin and acrylic is similar to that between polyester and the core materials. The Test Coupon Production Specification (Enclosure 1 of this Report) gives details for the incorporation of the plastic reinforcement into the laminate panels from which the test coupons are cut.

4.2 Flexural Testing

Preliminary testing using a 3-point flexure test based on Method I of ASTM D-790, with a 20" support span and a 3/4" dia. loading nose indicated that failures occurred on the compression side under the loading nose, and that those failures may have occurred prematurely due to transverse compressive deformation under the loading nose, especially for cored specimens.

The final test setup specified in the Test Procedure calls for a two-point loading arrangement similar to the 4-point flexure test of Method II of ASTM D-790. A load span of 1/4 the support span (5 inches in this case) and a loading nose diameter of 3" were specified in order to minimize the transverse compressive deformation of the coupon under the loading nose.

The maximum bending moment for this arrangement, which is constant over the load span, is $0.1875 \cdot P \cdot L$ as opposed to $0.25 \cdot P \cdot L$ for a load concentrated at the center. (P is the total bending load and L is the support span.) Thus, to achieve a maximum bending moment with the 1/4-span load which is equal to that produced by the centered load, the total load in the 1/4-span test must increase by 33% over that for the centered load test. Since this load is divided over the two loading noses, this results in a <u>decrease</u> in force <u>per loading nose</u> of 33%.

An additional advantage of the spanned-load configuration is that the maximum bending moment in the beam, and thus the bending stress and radius of curvature as well, are constant over the entire load span. This insures that the entire area around the defect is under the same level of stress. The use of the spanned-load also eliminates interference between local stress fields under the loading nose and the defect, and makes the experiment less sensitive to small errors in the positioning of the loading nose or in the positioning of the defect.

5 DEVELOPMENT OF THE TEST PLAN

A statistically based Test Plan, (Enclosure 3 of Volume II of this Report), was developed for use in conjunction with the Test Coupon Production Specification (Phase 1) and the Test Procedure (Phase 2). The Test Plan describes both overall and detailed strategies for determining the structural effects of defects. The overall strategy can be adapted to apply to any combination of tensile or flexural testing and any number and type of defects. The detailed strategy is based upon the testing of coupons of one solid and three cored constructions in tension and flexure having the 9 defect types specified in the TCPS.

The goal of the Test Plan is to screen all combinations of core and flaw types of interest and to determine the flaw size at which each flaw type/core type combination shows significantly lower strength than unflawed specimens of the same types. Those combinations having significant strength reductions are then tested over a range of flaw sizes to obtain curves of estimated breaking strength vs. flaw size. The tests proceed through the steps detailed below.

The overall testing strategy developed to achieve this goal is applicable to tensile and flexural testing, and the detailed strategy includes both types of testing.

The Test Plan comprises five steps:

Step 1 The variances of breaking strength for both flawed and unflawed specimens of solid construction and of one of the three cored constructions are determined in this step. Only one flaw size (the largest size deemed practical and meaningful) is used for all flawed specimens. This large flaw size is determined, for each flaw type, from the results of a width sensitivity study. It is assumed that the measured strengths of all three cored flaw types have equal variances. All specimens of a given flaw type, size, and core size are assumed to have normally distributed breaking strengths. The detailed testing strategy calls for a total of 624 specimens to be tested in this step.

Step 2 Sample variances for the groups of flawed and unflawed specimens tested during Step 1 are compared to determine of the population variances for flawed and unflawed specimens for each combination of flaw, core, and test type can be concluded to be equal. An F-test is used for this comparison.

Step 3 432 cored specimens are tested for each of the three core types and all flaw types. The largest practical flaw size, determined from the pilot test program, is used.

Mean strength values for the cored specimens tested in this step and for the solid specimens tested in Step 1 are computed.

Step 4 Mean strengths of flawed and unflawed specimens are compared in this step. Mean strengths for the different core types are also compared. T-tests are used to draw conclusions about the equality of population mean strengths.

At the conclusion of the four steps above, some of the core-type/flaw-type combinations may be eliminated. Those combinations for which the means and variances of the breaking strengths are not significantly different for flawed and unflawed coupons will be dropped from further consideration.

Step 5 A range of flaw sizes is tested for each remaining core type/flaw type/test type combination. The means and variances of the breaking strengths are computed, which will allow the relationship between minimum expected breaking strength and flaw size to be investigated. Twenty four specimens are to be tested for each core/flaw/test-type combination.

6 THE PILOT TESTING PROGRAM

6.1 Development Of The Pilot Program

The pilot test program involved tensile and flexural tests on 404 specimens exhibiting the 9 defect types listed in section 3.2. This program had several purposes:

- To validate the tensile and flexural testing techniques being specified in the Test Procedure.
- To evaluate the specimen production procedures specified in the Test Coupon Production Specification.
- To provide baseline information about the mean mechanical properties of unflawed specimens and about the variability of those properties - information which was necessary and valuable in the development of the full-scale Test Plan.
- To provide an initial rough indication of the effects of defects on the mechanical properties of the specimens.
- To assist with the identification of suitable dependent variables (specimen properties or material properties) to be used in further testing.
- To evaluate the significance of edge proximity effects in order to establish the maximum significant defect size for future testing.
- To provide data which would allow the evaluation of subsidiary relationships such as variations in the properties of unflawed specimens from one panel to another or with position in a given panel - information which might be of value in future test plan development.
- To develop and evaluate suitable techniques for efficient and effective collection and recording of test data.
- To identify and solve any unforeseen problems in testing before attempting a major test program.

The pilot test program comprised 72 individual experiments.

The experiment design followed the randomized block strategy. Aside from several exceptions necessitated by the logistics of the layup procedure, each experiment involved both flawed and unflawed specimens cut from the same panel.

The pilot test program included two major groups of experiments. One group of experiments was designed to study the effects of edge interactions. Two representative flaw types were chosen, simulated cracks, which interrupted the fiber continuity but did not cause any changes in dimensions or configuration, and voids, which did not interrupt fiber continuity, but did cause a bulge in the laminate skin. The experiments of this group tested coupons of three different widths up to 3-7/8", with each width having four different flaw sizes, ranging up to 2" in width. Unflawed coupons of each width were also tested. The four experiments tested both solid and Airex cored layups with simulated crack and void defect types. All tests in this group were flexural.

The other major group of experiments tested every combination of 7 different defects or flaws in each of the four layup types, both in tension and flexure. A typical experiment in this group involved six 3-7/8" wide specimens of the same layup type, tested in either flexure or tension, with two specimens unflawed, two having 1" flaws and two having 2" flaws. Two additional flaw types (lapped reinforcement and dirt inclusions) were tested with the defect covering the entire width of the specimen. These experiments were intended to verify the practicality of testing each of the chosen flaw types in each of the layup types in both tension and flexure. The results were intended to provide an initial rough indication of the relation between flaw size and strength reduction. In addition, since unflawed specimens were incorporated into each experiment, a relatively large pool of data was created for estimating the statistical parameters of the measured strengths of unflawed specimens for each of the four layup types in both tension and flexure.

Related Material in Appendix B "Pilot Test Program Documentation":

B1 Panel Layout Plans
B2 Randomization chart
B3 Randomization program

6.2 Pilot Test Program Testing Strategy

PART 1 - WIDTH SENSITIVITY TESTNG

These experiments were two-factor multilevel experiments in which the independent variables (factors) are the defect width and the specimen width. Five sizes of defects were used, 0, 0.5, 1, 1.5, and 2 inches, with specimen widths will take on 3 values (2.25, 3.125, and 3.875 inches). Every point on the 5x3 matrix was tested, with one unflawed specimen (0 defect width) and two each of 4 defect sizes for each specimen width. Thus a total of 27 specimens were tested per experiment, with four experiments, two for a solid laminate with two different defect types and two for an AIREX cored laminate, again using two defect types. Only flexural testing was done in this screening experiment.

Total 4 experiments (2 defects x 2 core types) x 27 specimens/experiment = 108 Specimens (96 flawed, 12 unflawed; all Flexural)

Defect types were simulated cracked skin and voids. These defect types were chosen because they represent two distinctly different types of defects, the cracked skin involves weakening of the reinforcement but no deformation of the laminate stacking, while the void involves no damage to the reinforcement but causes a bulge in the laminate.

PART 2 - DEFECT SIZE EXPERIMENTS

These experiments are single-factor experiments with defect size being the sole independent variable (factor) in each experiment. The defects will take on 3 values (0, 1, and 2 inches). All specimens will be 4 inches wide.

For 6 defect types (Voids, Uncured resin, Dry fiber, Delamination, Cracked skin, and Impact damage) 8 experiments will be conducted for each defect type (solid laminate and 3 cored laminate types, Tensile and Flexural testing), with each experiment involving 5 specimens (one with no defects and two each with 1 inch and 2 inch defects).

Total 48 experiments (6 defects x 4 core types x 2 test types) x 6 specimens/experiment = 288 specimens (192 flawed, 96 unflawed; 144 Tensile, 144 Flexural)

For core filling, 6 experiments will be conducted (3 core types, tensile and flexural), with each experiment involving 4 specimens (Two each with 1 inch and 2 inch diameter core fillings).

Total 6 experiments (1 defect x 3 core types x 2 test types) x 4 specimens/experiment = 24 specimens (all flawed; 12 Tensile, 12 Flexural)

For laps in the reinforcement and for foreign material inclusions (dirt), both of which cover the full width of the test specimen, 8 experiments per defect will be conducted with each experiment involving 2 flawed specimens.

Total 16 experiments (2 defect x 4 core types x 2 test types) x 2 specimens/experiment = 32 specimens (all flawed; 16 Tensile, 16 Flexural)

SUMMARY OF TESTS

PART 1 - 108 specimens - 36 each of 2.25", 3.125", and 4" widths. (96 flawed, 12 unflawed; All flexural)

PART 2 - 344 specimens - all 4" wide.
(248 flawed, 96 unflawed; 172 tensile, 172 Flexural)

Total of 404 test specimens (344 flawed, 60 unflawed; 148 Tensile, 256 Flexural)

6.3 Test Specimen Fabrication

Specimens were fabricated at the boatbuilding facility of Conrad Thomas, 1130 River Rd, Old Mystic, CT. The fabrication space was an insulated room with a gas-fired thermostatically controlled hot-air heating system. Preliminary specimens were fabricated in the period from December 18, 1991 to Feb. 5, 1992. Development of defect production techniques took place in January 1992, and entailed experimentation with a number of potential techniques and fabrication of sample defective specimens. In addition, a number of partial panels, not intended for test specimen production, were fabricated in order to develop standard layup conditions and procedures to be incorporated into the TCPS.

Specimens were cut from larger panels of laminate. A panel size of 38" wide (the standard width of fiberglass reinforcement fabrics) by about 76" long was established. This size allows one worker to lay up a panel without difficulty. Finished cored panels this size can be moved and handled by one person; solid panels require two people. Twenty-four standard test specimens (3.875" x 24") can be cut from each panel, leaving a suitable allowance for cutting and for discarding the edges and ends of the panel, where the layup is less uniform. The panel size selected allows all of the flawed and unflawed specimens for a given direct comparison experiment as defined in the Test Plan to be cut from the same panel, eliminating possible variations in mechanical properties between panels as a factor in interpreting experimental results.

Testing of preliminary Panels for cored tensile specimens must incorporate core fillers to prevent crushing under the grips of the testing machine. Acrylic sheet of the same thickness as the core material was used as a filler material. When the core was placed on the underlying layup, strips of acrylic sheet were laid in place with it. Details of the configuration are shown in illustrations accompanying the TCPS. It was found that different core types and both reinforced and unreinforced cored specimens (for tensile and flexural tests, respectively) could be mixed in a given panel without difficulty. The actual thicknesses of 1/2" acrylic sheet, and of the three 1/2" core materials vary only slightly from the nominal dimension, making mixed-core panels easy to produce. Cored and solid layups, however, could not be mixed.

Since most composite hulled vessels which require Coast Guard inspection must be built from fire-retardant resins, only fire-retardant resin was used in the production of test specimens. This resin is considerably more dense (10.5 lb/gal vs. 9 lb/gal, typically) than standard polyester laminating resin. It is also more viscous, making layup more difficult, and produces more heat during the gel period. It was considered good practice to maintain a 1% catalyst ratio by weight, using 9% active oxygen MEKP catalyst, in order to insure adequate cross-linking of the cured resin. In order to achieve this goal, several precautions were found to be necessary or advisable:

- The materials (fabric, resin, and reinforcement) must be kept at a temperature not above 60°F before use. Since the cure cycle is 24 hours at 72°F, materials may have to stored outside the layup and curing space in order to keep their temperature down if the layup of one panel closely follows the curing of another.

- Layup must be accomplished at a room temperature of about 60°F in order to allow a sufficient pot life.

- A low hydrogen peroxide catalyst which inhibits initial exotherm development while still allowing full curing was found to be appropriate for the fire-retardant resin.

The temperature controls mentioned above are particularly important for solid layups, in which a large mass of material is curing simultaneously, with consequently high heat production. Control over material and layup temperatures helps to keep the temperature of the laminate within allowable limits during the gel period. Extending the time between individual layers being laid down and saturated was also found effective in controlling excess heat buildup which would occur if a number of layers reached the gel point simultaneously.

Resin was mixed in one or two quart batches in uncoated paper pails which had been previously marked for the proper resin volume, and catalyst was measured into and dispensed from graduated polyethylene cups. Since the resin and the catalyst specified have different densities than standard non-fire-retardant resin and standard medium hydrogen peroxide content catalyst, it was necessary to calculate the required catalyst volume ratio, rather than referring to catalyst manufacturers charts, which are developed for standard materials. These calculations are detailed in the TCPS.

Production of specimens for the pilot test program took place between Feb. 2 and May 22, 1992. Records were kept of layup time, temperatures, and humidities; cure times, temperatures, and humidities; and of batch sizes, number of batches mixed, catalyst ratio used, and material sources for each panel. A detailed list of material origins was maintained for resin, catalyst, and reinforcing fabrics.

Related Material in Appendix B:

B4 Primary Material Source Information
B5 Panel Fabrication, Inspection, and Test Records

6.4 Testing

All mechanical testing for this project was carried out at the U.S. Army Materials Technology Laboratory (AMTL) in Watertown, Mass. Mr. Robert Pasternak, Materials Engineer for AMTL, supervised the testing.

6.4.1 Tensile Testing

Tensile Tests were conducted on an MTS 100,000 lbf capacity vertical servo-hydraulic testing machine with an 8" actuator stroke. The machine was equipped with a 100,000 lb. capacity hydraulic grip system, and a 300,000 lbf rated load-cell force transducer in the fixed crosshead.

Due to the possibility of slippage of the specimen in the machine grips during loading, the machine's built-in crosshead travel output was not used; instead, extension was measured by a strain-gage extensometer with a gage length of 2" attached to the center of the face of the specimen at the midpoint between the grips.

The output of the load cell was routed through the machine console to an OPTIMA 5517 Data Acquisition System. The extensometer output was fed through an amplifier/conditioner to the same A/D converter. Data was initially stored on an optical disk in the Data Acquisition system, then downloaded into the fixed disk of an IBM PS/2 desktop computer.

The loading rate during tensile tests was controlled at a constant 0.12 in/min.

6.4.2 Flexural Testing

Flexural tests were conducted on an INSTRON 50,000 lb. electro-mechanical tension-compression machine. This machine has a load cell force transducer in the movable crosshead. The transducer is rated 50,000 lb with multiple ranging capability. The $\pm 10V$ analog output of the load cell is routed to the machine console, then to the same Data Acquisition System used for the tensile testing. Deflection of the flexural specimen is measured by a linear variable differential transformer (LVDT). The LVDT body was mounted to the base of the machine and movable measurement rod was clipped to the specimen at the center of the load span (which is also the center of the support span and the center of the specimen). The LVDT output, after being converted to an analog DC signal by the LVDT control electronics, is routed to both a digital readout device on the machine console and to the Data Acquisition system.

A standard roller-type flexural support structure was mounted to the base of the testing machine. The 1.25" dia. roller supports were spaced 20.25" apart, center to center. The specimens were loaded by means of a two-nose loading assembly which rested on the specimen and which was in turn loaded by the machine crosshead. The loading noses were 3" diameter and were 5.0" center to center (1/4 of the support span). Flexural specimens were loaded at a constant rate of 0.5 in/min, controlled automatically by the testing machine.

Flexural specimens were positioned in the testing jig with the top face as manufactured facing down (on the tension side of the bend). Since all of the intentionally introduced defects were on the top side of the panels during manufacture, the defects were all on the tension side.

6.5 Analysis Procedures

All analyses use the scaled breaking load (breaking load per unit width of the specimen) as the property of comparison. The reasons for selecting this property over other potential properties for comparison are explained in section 6.4.1 of this Report.

The scaled breaking load is computed by dividing the measured breaking load by the average of the three specimen width measurements, taken as specified in the Test Procedure.

6.6 Technical Discussions: Analysis of Experimental Data

6.6.1 Specimen Properties vs. Material Properties

The fundamental nature of this testing program, or any other, is a comparison of properties. In this case, the comparison is between the mechanical properties of flawed and unflawed specimens. One of most significant decisions in the analysis of the results of a testing program is the identification of the dependent variables - the properties to be used as a medium of comparison. For this project, that decision requires a choice between specimen properties and material properties.

Based upon a number of points which will be raised in the following discussion, specimen properties, specifically, breaking load per unit width, will be used as the primary comparison between flawed unflawed specimens in the analysis of these experiments, and it is suggested that this course be followed in the analysis of data from subsequent experiments as well.

As with any mechanical test technique, the raw test data are *specimen properties*, that is, they measure quantities unique to the particular specimen being tested, and to the test performed. Specimen properties are measured directly. The ultimate goal, however, of most mechanical testing is to determine *material properties*. Material properties are calculated from measured specimen properties in such a manner that those components of the specimen properties which are due to the dimensions or other characteristics of the individual test specimen or which are due to the nature of the testing procedure are separated from the basic properties of the material itself. These material properties can then be compared against established standards or mean values or against properties which have been obtained by testing different specimens, possibly by different test methods.

In tensile testing, the specimen dimensions, the load/elongation curve, and the load and the elongation or strain at both the failure point and at the proportional limit are typical measured specimen properties. From these, certain material properties, usually the failure and proportional limit stresses and the elastic modulus are calculated.

In flexural testing, the specimen dimensions, the load at the proportional limit and at failure, the deflection at the proportional limit and at failure, and possibly, the strain of the surface fibers are the principal measured specimen properties. Material properties which are calculated from these include the outer fiber stress at failure and at the proportional limit and the flexural modulus.

If the techniques by which material properties are inferred from specimen properties were perfect, then testing methods would be effectively transparent, and the failure and limit stresses calculated by tensile and by flexural testing would be equivalent for a given material, as would the flexural and tensile moduli; this is rarely the case in practice, and is virtually never the case for composite materials.

The calculations that lead from specimen properties to material properties are based upon assumptions that the load-carrying material in the specimen has constant properties and is uniformly distributed, that is, that the material is *homogeneous*. The calculation of certain material properties also requires an assumption of *isotropy*, or equal properties in all directions, as well.

In converting tensile load data to tensile stress, for example, the assumption must be made that the load-carrying ability of a finite-width specimen is directly and linearly proportional to its cross-sectional area, which is the same as assuming a uniform distribution of load-carrying capability throughout the cross-section (homogeneity), and a uniform distribution of stresses across the specimen width (which generally requires isotropy).

In the case of flexural test data, the assumptions of homogeneity and isotropy lead to the additional assumption that linear elasticity theory applies, that is, that the stress and strain below the proportional limit vary linearly through the depth of the load-carrying material. This leads to the conclusion that the highest levels of stress and strain occur in the outer fibers during bending.

For materials like metals and unreinforced plastics, assumptions of homogeneity and isotropy are generally fairly valid, and material properties can be quite reliably determined from simple tensile and bending tests. Laminated reinforced plastics, however, are neither homogeneous nor isotropic. Prosen (1969) points out that material properties of composites determined by mechanical testing techniques originally developed for homogeneous are often not meaningful.

THE EFFECTS OF HETEROGENEITY ON CALCULATED MATERIAL PROPERTIES

Reinforced plastics are highly heterogeneous. The reinforcement fibers and the plastic matrix have greatly different properties. The fibers have a much higher modulus than does the matrix material, resulting in almost all of the loads being carried by the fibers. The internal structure alternates between layers in which reinforcing fibers predominate and layers in which the matrix material predominates. The fiber direction, twist, and density in the reinforcement layers may (and generally do) differ from layer to layer, as well. The ratio of matrix material to reinforcement material varies not only from layer to layer within the laminate, but can also vary considerably between specimens and from one general area to another on a given specimen.

For a homogeneous material, an increase in cross-section necessarily implies a linearly proportional increase in the amount of load-carrying material. For composites, this is not necessarily true. For fabric-reinforced materials in which the number of reinforcement layers and the type, amount, and alignment of fibrous reinforcement material in each layer are fixed, variations in certain physical properties of the laminate can affect the thickness of the laminate without proportionally affecting the load-carrying ability. These physical properties are:

1. The reinforcement/matrix ratio (the glass/resin ratio).
2. The void content.
3. The thickness of surface resin layers.

Zweben, Smith, and Wardle (1979) point out that local variations in the glass/resin ratio and in the thickness of surface resin layers have little effect upon the breaking load of laminates, which is primarily dependent upon the cross-section of reinforcement.

Material properties, in general, are calculated by dividing a load by a function of the thickness (the cross-sectional area, the moment of inertia, or the section modulus are all functions of the thickness). If thickness can vary without corresponding changes in load-carrying ability, the calculated material properties remain functions of the particular specimen and lose their significance.

In the case of tensile testing of composites, the tensile load-carrying ability and the load-vs.-extension properties of a specimen are determined almost entirely by the cross-section of reinforcement. The physical properties mentioned above have little effect on load-carrying ability but, since they affect the thickness, they do affect the calculated values of the failure and proportional limit stresses and the modulus.

For flexural testing, the situation is more complex. The physical properties, by affecting the depth of the section, affect the moment of inertia and thus the bending stiffness, so an increase in thickness due to physical properties results in a shift in the load/deflection curve without any change in the actual amount of load-carrying material. That change in the load-deflection due to the increased depth (thickness) of the specimen is not the same as the shift which would occur if the same thickness increase had occurred at constant levels of the physical properties, that is, with a change in the amount of fiber reinforcement proportional to the change in thickness.

THE EFFECTS OF ANISOTROPY ON CALCULATED MATERIAL PROPERTIES

In addition to being heterogeneous, laminated reinforced plastics are also quite highly anisotropic. The reinforcement fibers, which are the primary factor affecting mechanical properties, have definite directional alignment. This results in the overall specimen having significantly different properties in different directions. In addition, various layers of reinforcement fabric in the laminate have different directional properties, resulting in anisotropy on another, smaller scale as well. These anisotropies affect the distribution of stress across the specimen, with the stress being considerably different near a free edge than near the center in both tensile and flexural specimens (Christensen 1991, Whitney 1973). The vertical stress distribution is also affected; bending stresses may not vary linearly throughout the depth of the material, and the maximum fiber stress in bending may not necessarily occur in the outer fibers (Whitney, Browning, and Mair 1973).

There are several other factors which adversely affect the significance of calculated material properties as a means of comparison. They are:

- The inclusion of defects further confuses the meaning of the various sectional properties required for calculation of material properties: for example, how the displacement of the reinforcement which accompanies a void affects the effective cross-sectional area or the section modulus.

- Transverse shear deflection is a significant factor in the bending of composites. Zweben, Smith, and Wardle (1979), Whitney, Browning, and Mair (1974), and Halpin et al (1969) point out that deformation due to shear can have a significant effect on the calculated flexural strengths and moduli because the ratio of shear modulus to longitudinal elastic modulus is low for most composites. The effects of transverse shear can be minimized by using large aspect ratios (support span/coupon thickness ratios). However, the ideal aspect ratio for testing flexural breaking loads (about 16:1) is far different from the ideal aspect ratio for testing flexural moduli (about 60:1) (Zweben et al 1979).

- For cored test coupons, especially those with plastic foam cores which are cut from larger panels and have exposed edges on the sides and ends, elastic and plastic longitudinal shear in the core has been observed to be a significant factor in bending. Core shear makes the test coupon easier to deflect, leading to unrealistically low values of flexural modulus, and also affects failure characteristics, allowing unrealistically large deflections at failure. Whitney et al (1974) point out that the interlaminar shear stress can be a factor even in flexure experiments on solid specimens. It is expected to be a much more important factor for foam-cored specimens.

COMPARISONS OF SPECIMEN PROPERTIES

Due to the anisotropic and heterogeneous nature of composite materials, the calculated material properties, especially those resulting from flexural testing, are of limited value except as a means of comparing the properties of test coupons having exactly the same physical properties (in other words the same total thickness). Thus there is really no reliable method of comparing the properties of specimens having different physical characteristics. If only specimens having similar physical properties are to be compared, then it is reasonable to use specimen properties for comparisons.

The only meaningful experimental variable which directly affects the specimen properties in a nearly linear fashion is the specimen width. Accordingly, load per unit specimen width appears to be the most logical quantity to consider in comparing defective and nondefective test coupons. Depending upon the goals of the analysis, this load could be the failure load, the proportional-limit load, or both.

For the reasons detailed above, breaking load per unit of specimen width principal quantity of comparison for all analyses of test data in this project.

6.6.2 Free Edge Effects

Test coupons are cut from panels of laminate, leaving bare edges which expose the entire laminate structure. In an actual hull, the edges are often flanged, they may be gradually reinforced with extra layers of fabric, they are often bonded or fastened to the edges of other panels, and cores are generally tapered out into solid laminates at edges rather than being exposed. Structurally, the edges of hull panels are often stiffened by reinforcement, by their curvature, or by connection to adjacent structural members in such a manner that significant bending deformation is impossible there. Abrupt termination of reinforcement in an area of high stress or frequent large deformation is rare and avoided whenever possible in actual hull design and construction.

For a coupon cut from a larger panel, however, any long reinforcing fibers in the ±45° or 90° directions and many of fibers in mat layers terminate abruptly at the edge of the coupon. The presence of a free edge in the zone of maximum stress creates a highly unrealistic situation. Whitney (1973) points out that the state of stress within one laminate thickness of the free edge in tensile and flexural coupons is significantly affected by the presence of the edge for specimens with 0/90° reinforcements, and that angle-ply reinforcements (±45° orientation) further complicate the problem.

The proximity of defects to a free edge in a stressed region is also unrealistic, and any interaction between defects and edges can lead to incorrect conclusions about the effects of defects on large panel strengths. Pipes, Kaminski, and Pagano (1973) point out that premature ruptures often occur in angle-ply laminates (those containing significant reinforcement in the $\pm 45°$ directions, as do the specimens for this test program) as a result of free-edge interactions. Whitney, Browning, and Mair (1974), in their analysis of the ASTM D-790 Flexure Test show theoretically that the state of stress within approximately one laminate thickness of the free edge is not equivalent to the stress assumed in the calculations of material properties based upon test results, and recommend as large a ratio of coupon width to depth as possible in order to minimize the effects of this phenomenon. This project uses realistic hull sections having large thicknesses by materials testing standards, and specimen widths are limited by testing machine capacities; thus, coupon width/thickness ratios sufficient to minimize edge effects are not realizable.

Christensen (1991) gives an excellent discussion of free-edge effects in composites.

6.6.3 Free-end Effects and Longitudinal Core Shear

Preliminary flexural testing of plastic foam cored specimens with centered loads indicated that a large amount of longitudinal shear occurred in the core. The use of a spanned-load arrangement decreased the amount of core shear, but significant amounts of longitudinal core shear can still be expected in foam-cored flexural specimens. The presence of bare free ends on these specimens allows longitudinal shear deformation to occur in the core without any outside resistance. This constitutes an unrealistic situation, since in a large hull panel subject to deformation in one area, the skins are not completely independent, and core shear is at least partially constrained.

Core shear could be nearly eliminated, if this was considered desirable, by incorporating a rigid core filler near the ends of the coupon beyond the support points, similar to the core fillers used in tensile coupons to prevent core crushing. However, complete elimination of this phenomenon would also constitute an unrealistic situation, as a certain amount of longitudinal shear does occur during the bending of large foam-cored panels.

6.6.4 Extrapolation of Coupon Test Results

The validity of estimating of the effects of defects on the properties of large hull panels by the testing of defective rectangular test coupons is uncertain. There has been very little research work done on relating coupon properties to hull panel properties. It is entirely possible that a defect type or size that causes a significant reduction in coupon strength does not cause a significant reduction in hull panel strength.

7 WIDTH SENSITIVITY EXPERIMENTS

One of the primary factors affecting the validity of using coupon test results to predict the properties of larger panels is the presence of free edges in the stressed area of the coupon. A significant part of the pilot testing program was devoted to a width sensitivity study, which was intended to clarify the relation between coupon width and strength for unflawed specimens, and to indicate any tendency for interactions between defects and the stressed edges of test coupons.

7.1 Experiment Strategy

Four experiments were conducted in order to attempt to evaluate the effects of the proximity of defects to the specimen edges. In the actual case of a defect in a vessel hull, the defects would generally not be in close proximity to an edge which is aligned with the principal stress direction, as defects in test coupons are. These experiments were designed to assess the effects of interaction between the defects and the coupon edges.

Since the calculated strengths are not adjusted for the reduction of load-carrying material caused by the presence of defects, it is expected that the strengths of coupons of a given size will decrease as the defect size increases. If the reduction in strength is entirely due to the reduction in load-carrying ability caused by the defect, it is expected that the decrease in strength will be approximately linear with increases in defect width for a given coupon size. For the specimens tested, the [defect size/specimen width] ratio is significant, as great as 50% in the main body of experiments and up to 88% in the width sensitivity experiments. It is possible that stress concentrations due to the proximity of defects to the edge of the specimen are a second weakening factor, in addition to the basic weakening effect of the defect alone. Such a nonlinearity or synergistic effect is referred to as an **interaction** in experimental terminology. If such an interaction exists, the strength can be expected to fall off more than linearly with increasing defect size.

Each of the four width interaction experiments was conducted on coupons cut from a single panel (one panel per experiment), in order to eliminate the effects of variations in properties between panels. All testing for these experiments was flexural and defects were placed on the bottom, or tension side of the bend.

The four experiments were:

- o Exp. A1 Solid coupons with voids.
- o Exp. A5 Solid coupons with simulated cracks.
- o Exp. B1 Airex cored coupons with voids.
- o Exp. B5 Airex cored coupons with simulated cracks.

Each experimental group consisted of 27 specimens, all from the same panel, having three different widths, 2.25", 3.07", and 3.88" (the same width as the specimens for the main group of experiments). For each width, there was one unflawed coupon, and two each with 0.5", 1.0", 1.5", and 2.0" defects.

7.2 Analysis of Experimental Results

The width sensitivity experiments were four experiments with 27 specimens in each experiment. All tests were flexural. The purpose was to evaluate the significance of edge effects in order to recommend a maximum defect size/coupon width ratio for further testing.

A separate analysis was conducted for each experiment. The analysis consists of plots of average strength (calculated as breaking load per unit width) plotted against flaw size, specimen width, and flaw size/specimen width ratio.

The analysis of the results of the width interaction study was based upon graphical presentations of the experimental data. As with all data analysis for this project, the breaking load per unit specimen width was used as the primary indicator of strength.

Three different plots are presented for each experiment. In the first plot for each experiment, the Strength indicated by breaking load per unit width (x-axis) is plotted against the 3 specimen widths (y-axis), with a separate curve shown for each of the 5 flaw sizes. The individual data points are shown and are connected by an interpolating spline.

If there were no interaction between flaw size and specimen width, these curves would be expected show a slight rise in strength with increasing specimen width, since the proportion of load-carrying material affected by the defect decreases as width increases for a given defect size. Curves for specimens having larger flaws would be expected to lie below, but more or less parallel to, those for smaller flaws, due to the increased weakening effect of the larger flaws.

In the case of an nonlinear interaction between flaw size and specimen width, the curves for specimens with larger flaws would be expected not only to lie below those for smaller flaws, but to slope with respect to them as well, and the individual lines would be expected to curve, rather than being straight.

In the second type of plots, strength (y-axis) is plotted against the five flaw sizes (x-axis), with a separate curve for each of the three specimen widths. The data points are shown and are connected by an interpolating spline.

In the case of no interaction, each of the three curves would be expected indicate a more or less linear decrease in strength with increasing defect size at each specimen width, and this drop should be somewhat greater for narrower specimens than for wide ones.

In the case of an interaction, the flaw size/specimen width ratio would be a significant weakening factor in addition to the flaw size alone, and the curves for narrower specimens would be expected to curve down noticeably at larger values of defect size, especially for narrow specimens.

The third type of plots show [strength (y-axis)] vs. [flaw size/specimen width ratio]. The average values for group of specimens with a given flaw size and a given width are the data points. There are twelve combinations of flaw size and specimen width, as well as unflawed, giving thirteen data points. The points are shown and fitted by a second-order least-squares regression line.

With no interaction, the strength is expected to fall slightly and linearly with increasing flaw/width ratio.

In the case of an interaction, the strength should fall off more than linearly with increasing flaw/width ratio, which would be indicated by a downward sloping and downward curving line in the plot.

7.3 Plots of Width Sensitivity Data

Figures 1 through 12 are plots of data from the width sensitivity experiments.

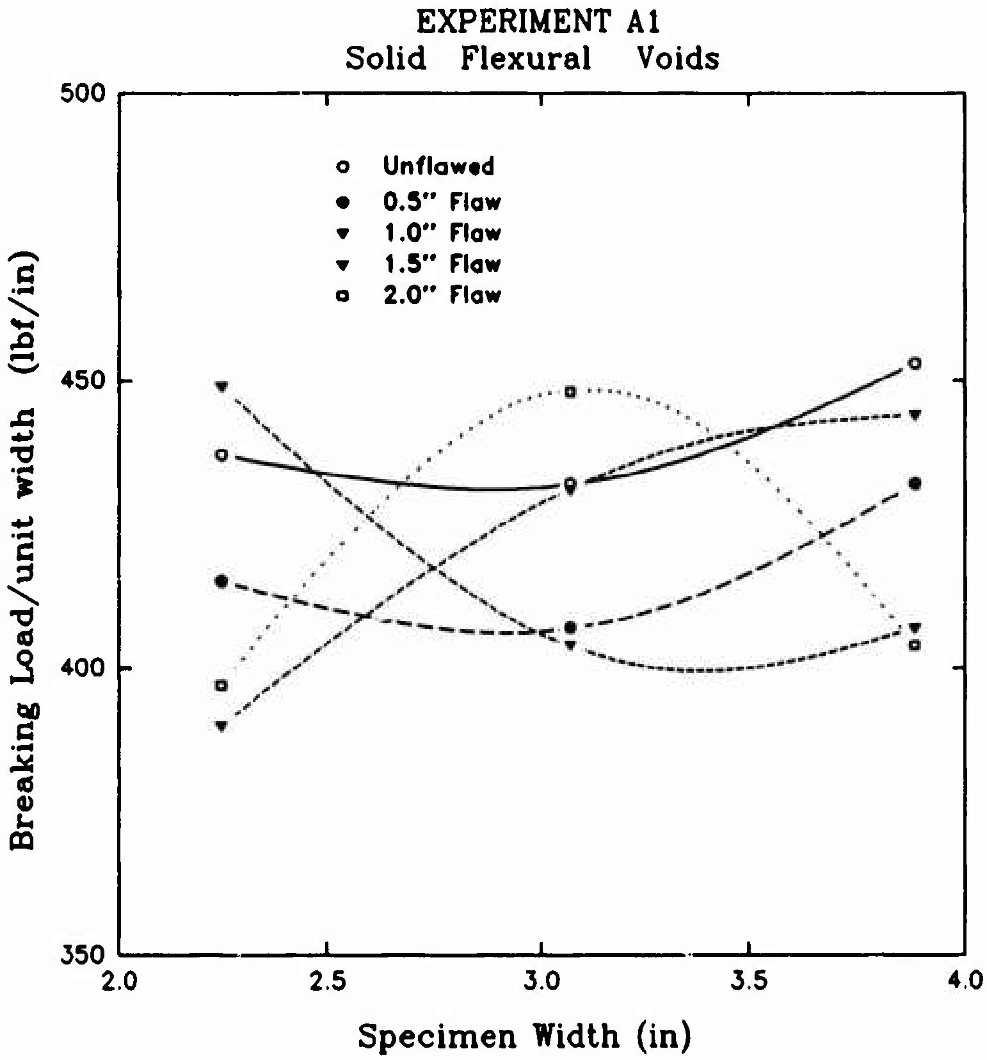

Figure 1 Strength vs. Specimen Width - Experiment A1

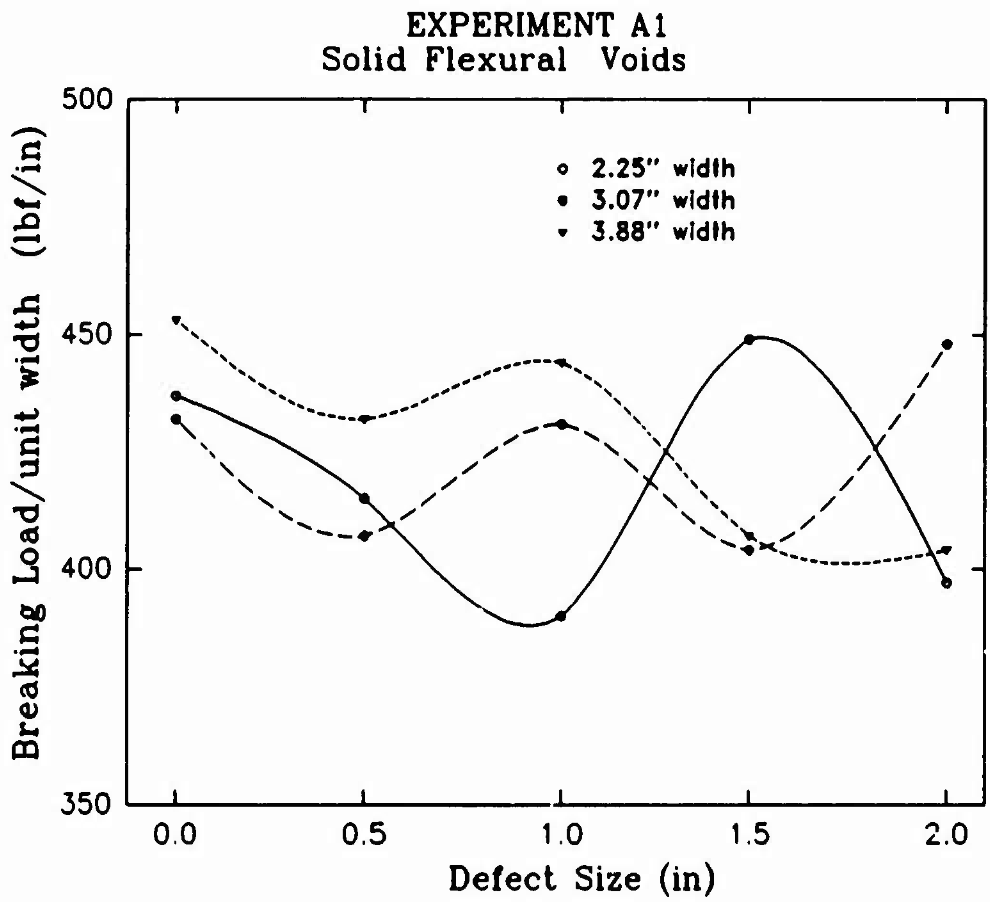

Figure 2 Strength vs. Defect Size - Experiment A1

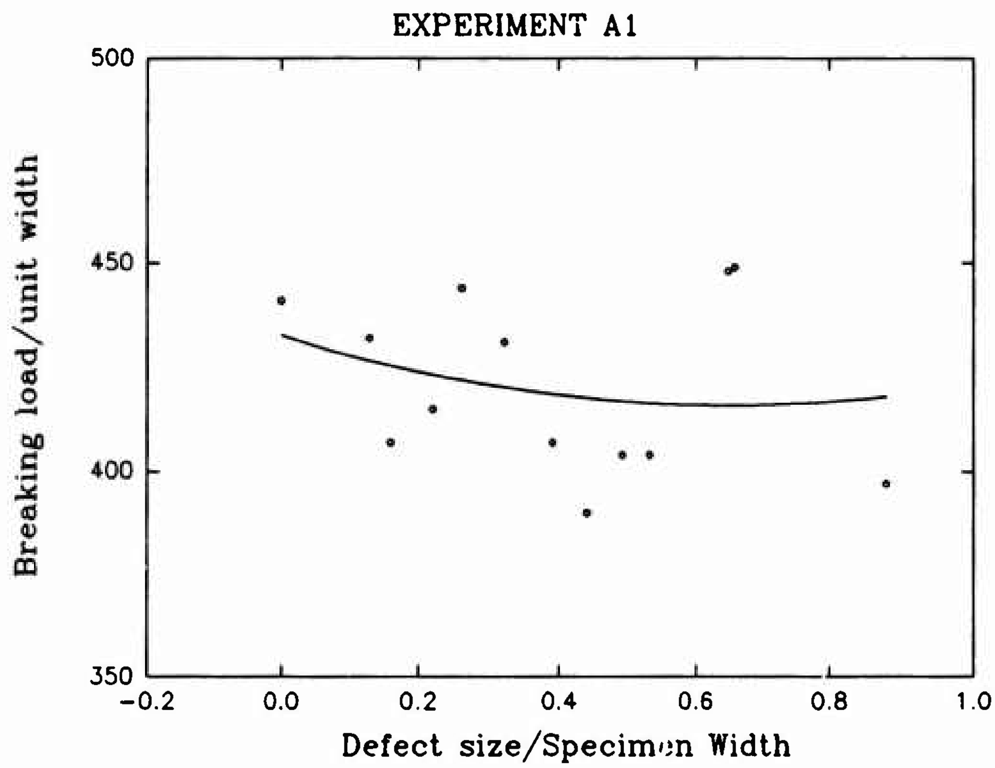

Figure 3 Strength vs. Defect Size Ratio - Experiment A1

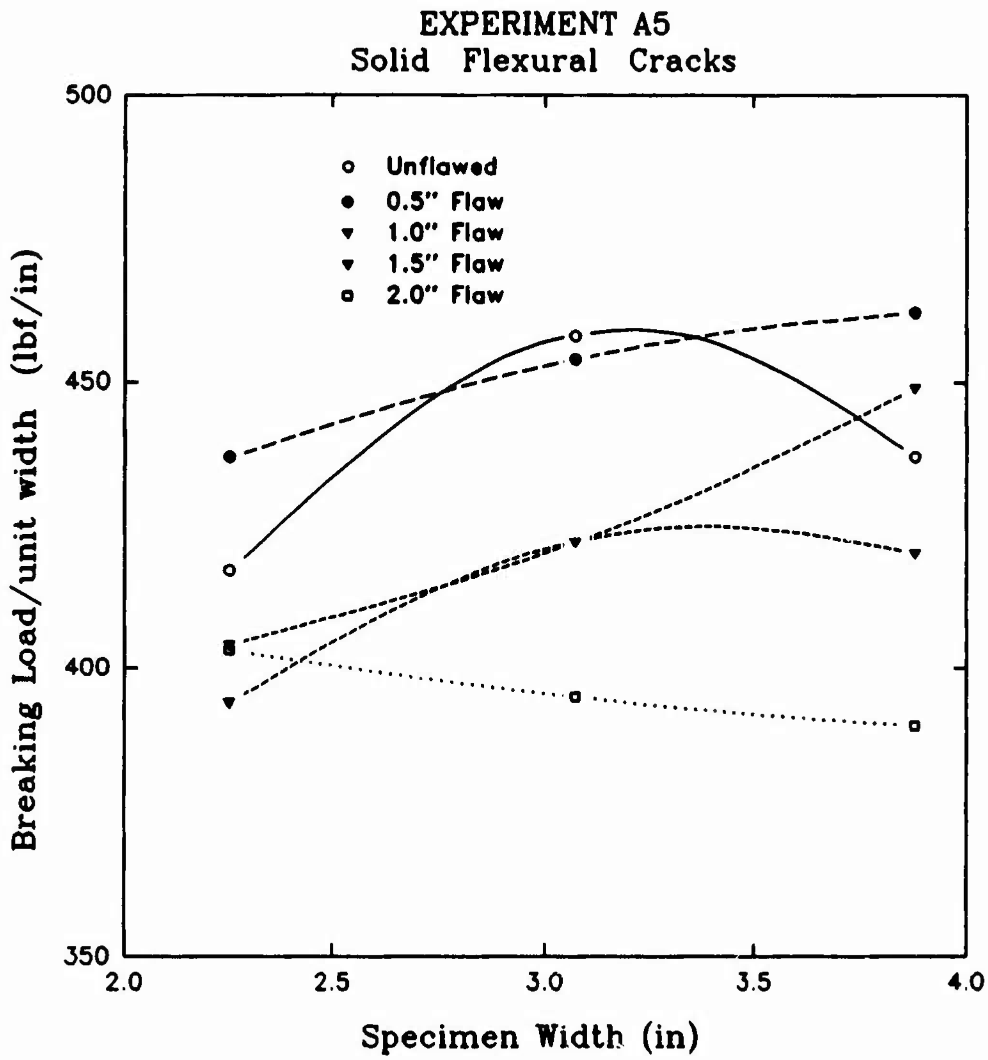

Figure 4 Strength vs. Specimen Width - Experiment A5

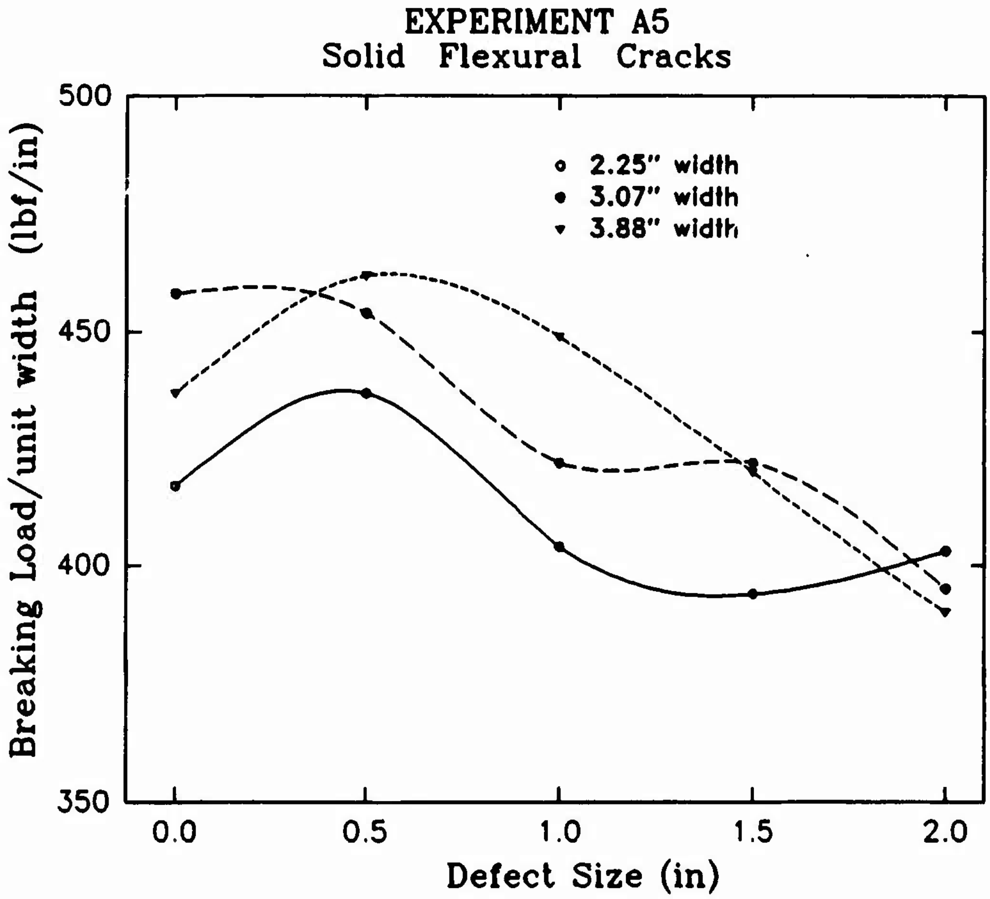

Figure 5 Strength vs. Defect Size - Experiment A5

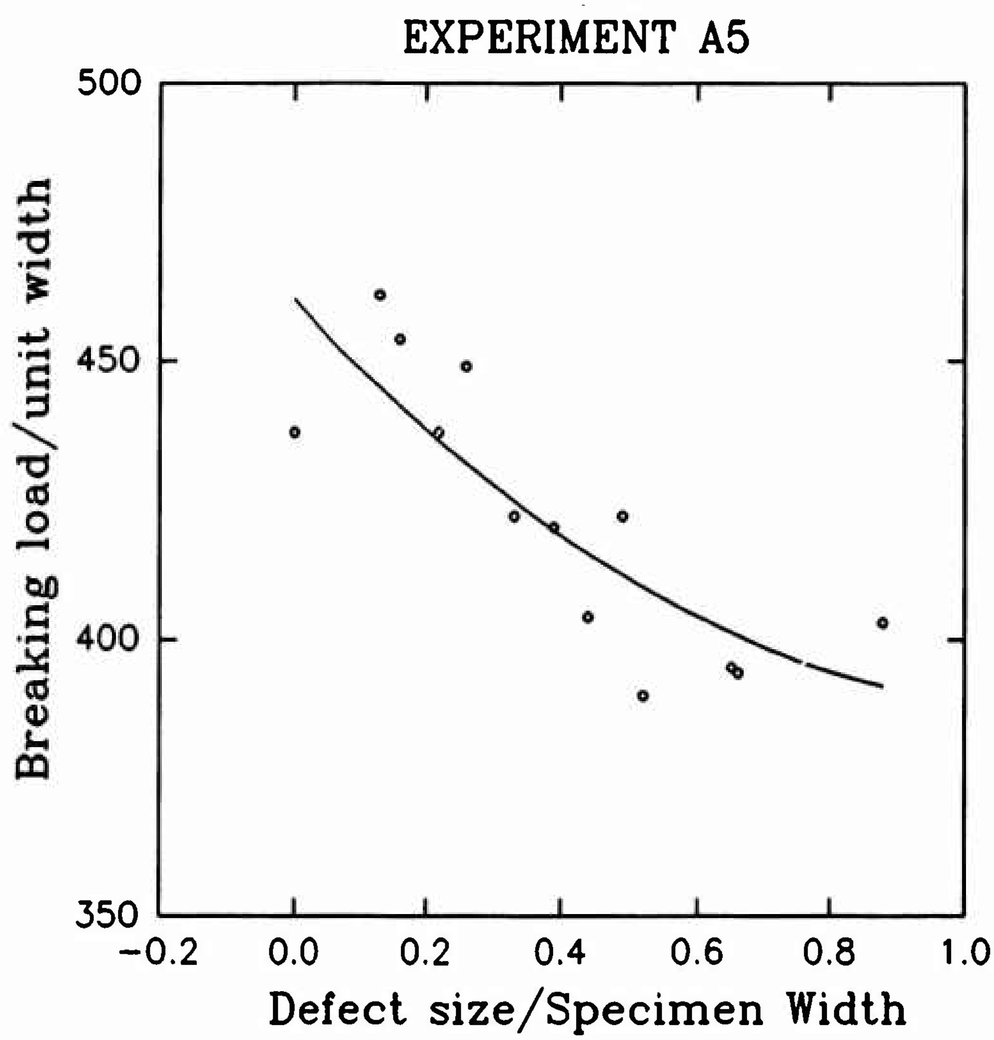

Figure 6 Strength vs. Defect Size Ratio - Experiment A5

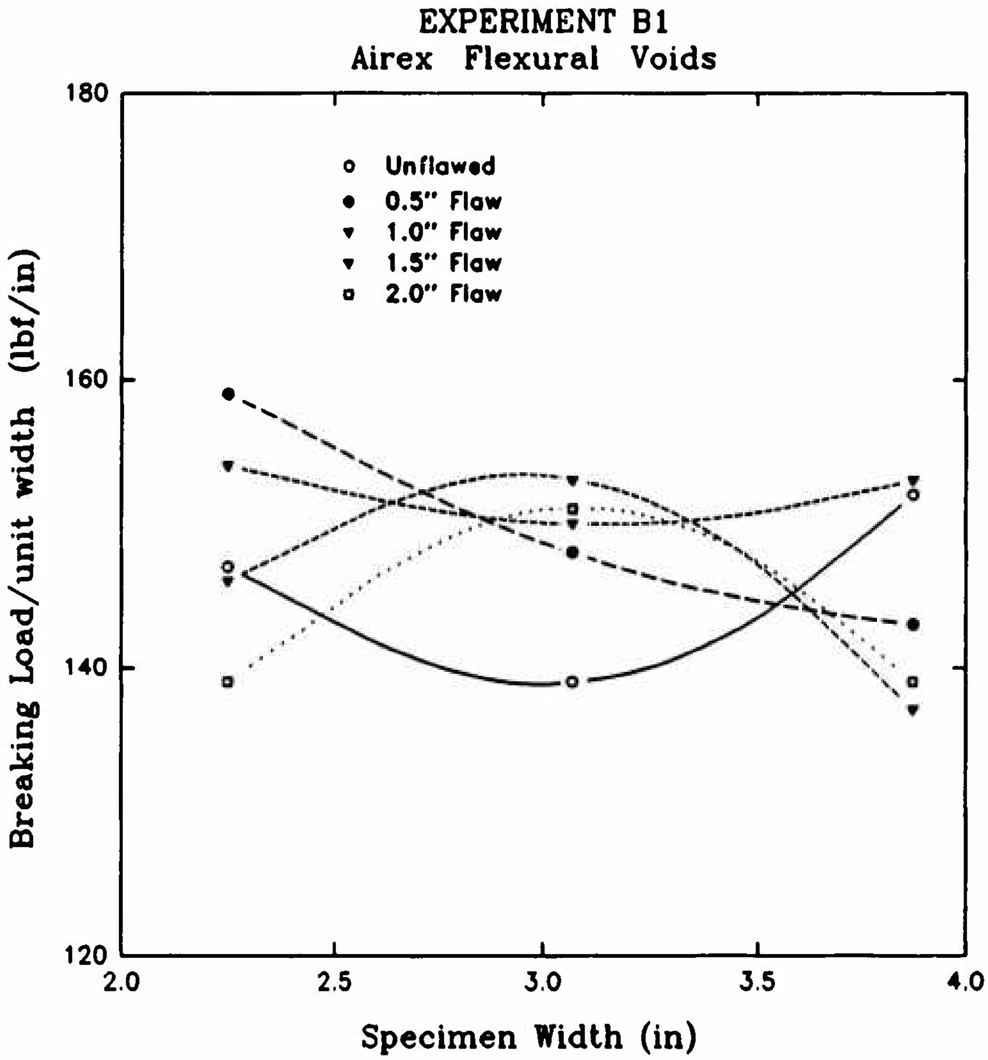

Figure 7 Strength vs. Specimen Width - Experiment B1

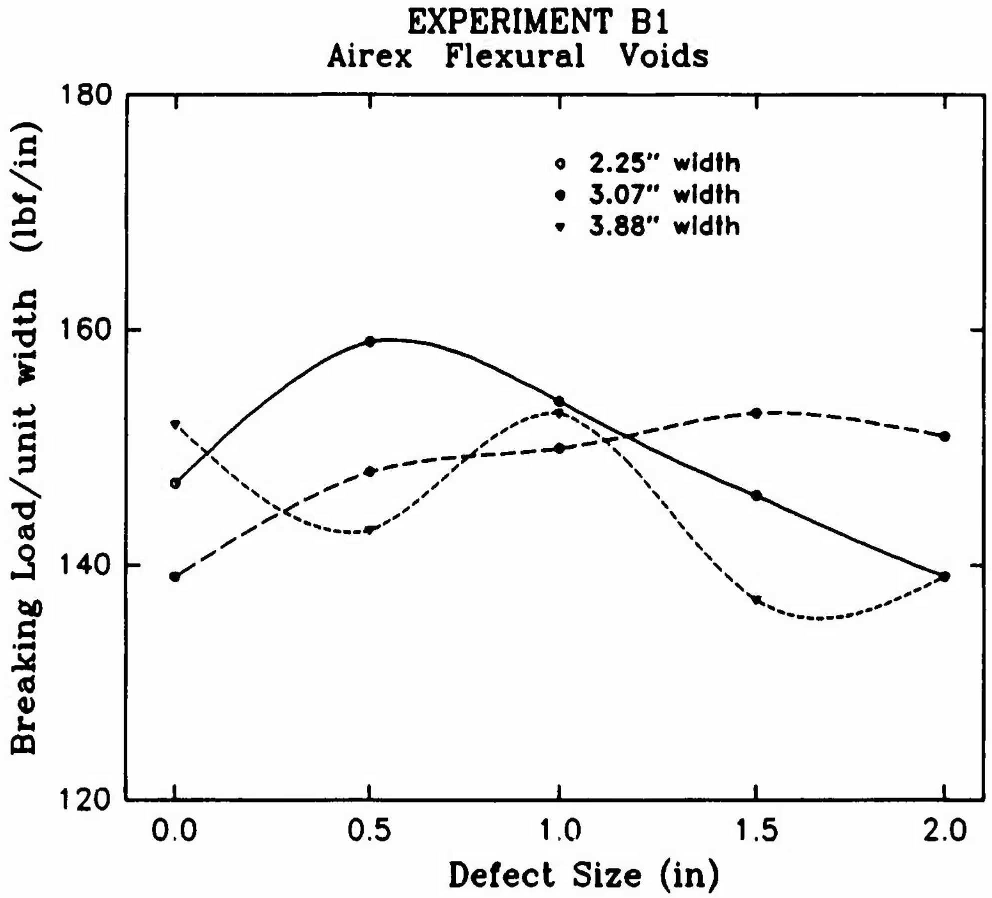

Figure 8 Strength vs. Defect Size - Experiment B1

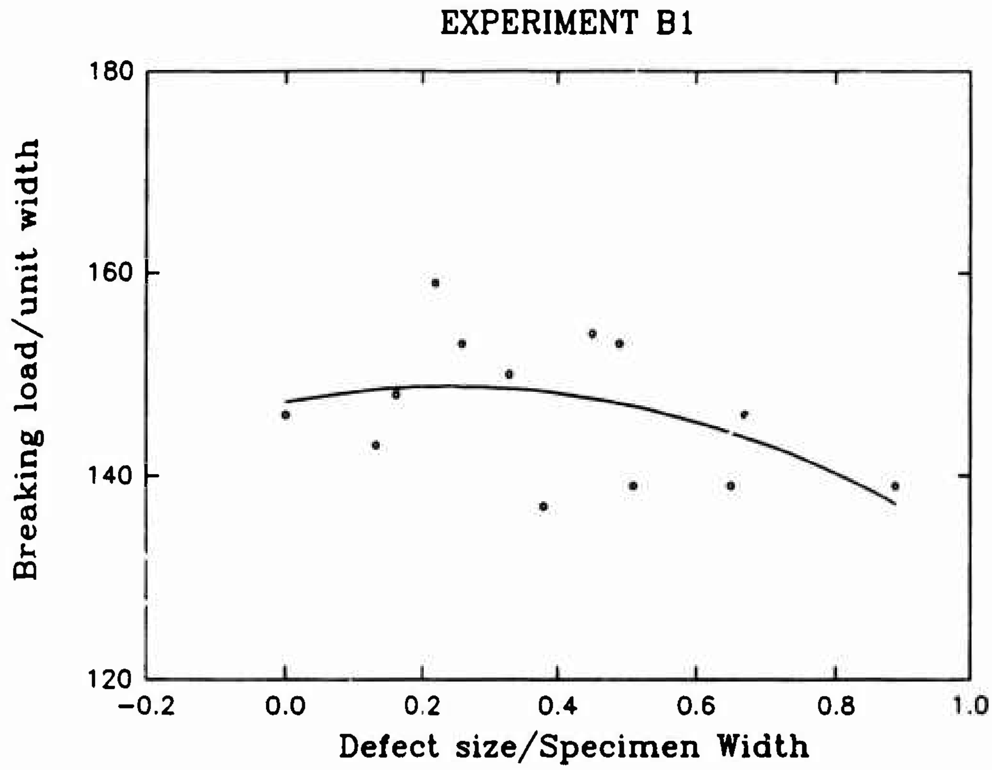

Figure 9 Strength vs. Defect Size Ratio - Experiment B1

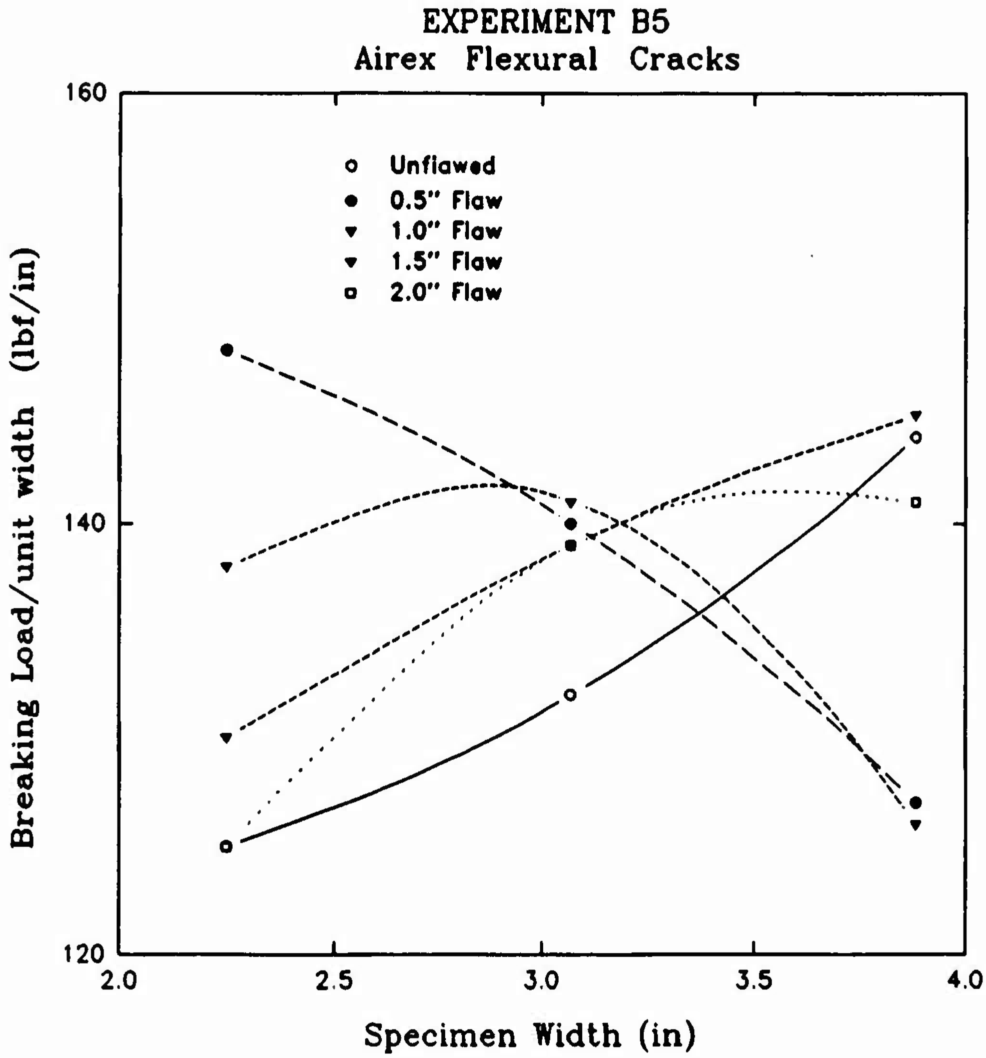

Figure 10 Strength vs. Specimen Width - Experiment B5

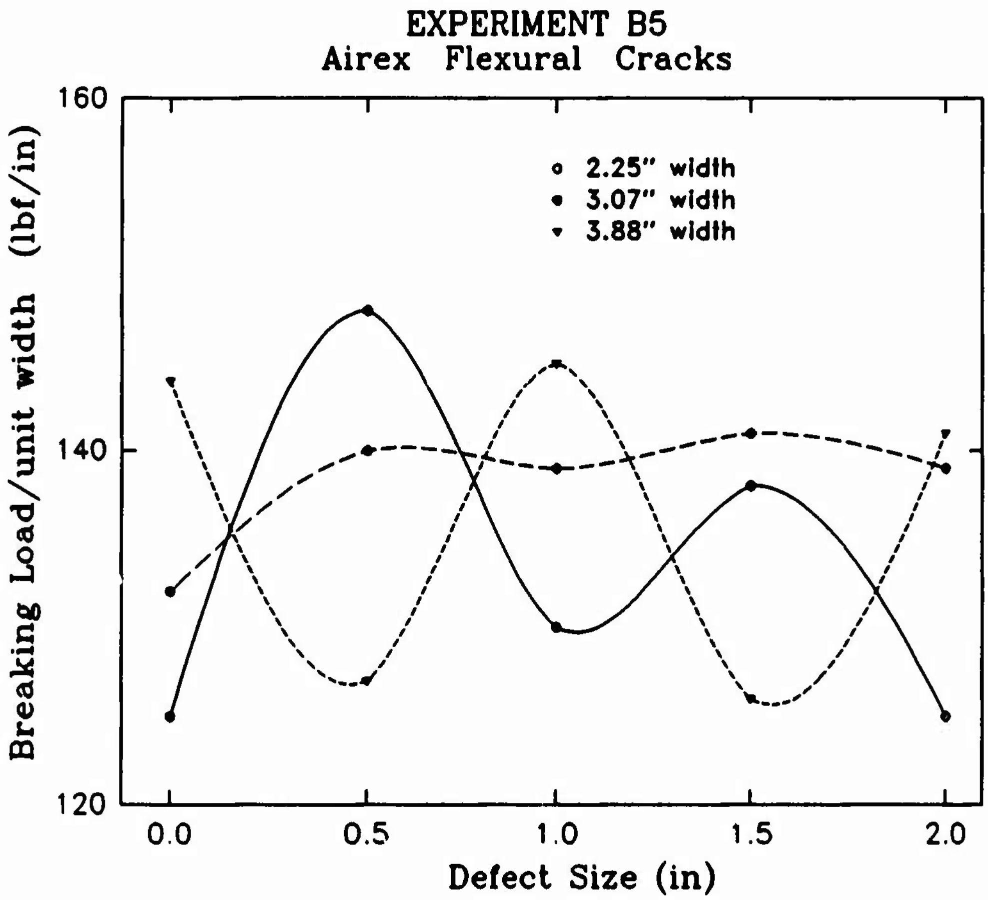

Figure 11 Strength vs. Defect Size - Experiment B5

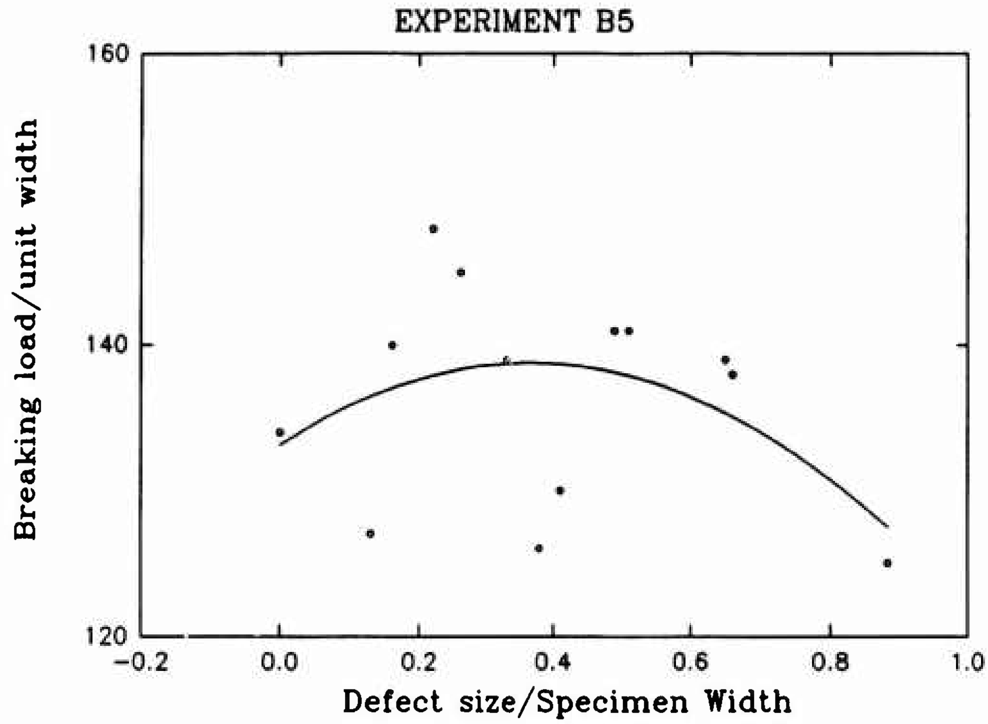

Figure 12 Strength vs. Defect Size Ratio - Experiment B5

The data sheets for the width sensitivity experiments, which provided the data for the above plots, are presented in Appendix C1.

7.4 Conclusions

Figures 1 through 12 show no definitive evidence of interactive effects. In general, the signal-to-noise ratio in these results is too small to justify any conclusions, either positive or negative, about the existence of interactions between defect size and width.

Two general trends appear in the [strength-vs-defect size] plots:

- The strength of unflawed specimens appears to increase with width. Such an effect is expected when angle-ply reinforcement layers are used in a laminate; strengths of composite specimens having angle-ply reinforcement are known to be significantly width-dependent. Thus, the use of angle-ply reinforcement may obscure other effects. As the specimen width becomes narrower, the effective fiber length decreases accordingly for angle-ply layers, thus decreasing the apparent strength.

  For flaw sizes other than unflawed, there is no discernible relation between strength and specimen width for a given flaw size.

- The strength of flawed specimens shows a slight tendency to decrease with increasing defect size. This is an expected result due to the effect of the defects alone and does not indicate any edge interactions, and it is only weakly indicated by the data.

The [strength vs. specimen width] plots indicate the following:

- For solid specimens, the strength appears to increase slightly with increasing specimen width for a given defect size. This is also an expected result which does not indicate any interactive effects, and it is only weakly indicated.

The [strength-vs-(defect size/specimen width)] plots indicate the following:

- There is a general tendency for strength to decrease with increases in the [defect size/specimen width] ratio. The plot for Experiment A5 (cored with crack defects) shows a strong drop in strength with increasing defect size ratio. This effect may be caused by defect size alone with or without any interactive effect.

7.5 Summary

The significant random variability in experimental results prevents any meaningful conclusions from being drawn about interactive effects between defect size and specimen width due to the small sizes of the samples tested.

In order to evaluate the effects of defects in large panels by testing narrow coupons, it is important that the testing avoid defect size/specimen width ratios at which significant interactions exist between defects and the specimen edges. The preliminary test results reported here do not support any definitive conclusions about such interactions. Further tests to determine such interactions will require much larger sample sizes than those used here, which might necessitate the use of specimens from more than one panel.

It is suggested that if further studies are conducted, all specimens from a given panel have the same width and the same defect type with the only variation within the panel being defect size. If the specimen width were 2.5" and 5 defect sizes were used, each individual this would allow 39 specimens per panel, eight for each of four defect sizes and seven unflawed. If additional specimen widths were desired, these would be cut from other panels.

An alternative to the testing of narrow specimens (with the attendant need to define interactions) would be to test specimens in which there is no free edge in the stressed region. This could be accomplished by the use of circular specimens. This possibility is discussed further in Section 7.2 of this Report.

8 DEFECT SIZE EXPERIMENTS

8.1 Statistical Considerations

Most of the experiments described in this section used two specimens of a given defect size (six specimens total, with two each of unflawed, small and large defect sizes). The standard deviation of strength for unflawed specimens ranged from 4% to 8% of the mean strength for tensile specimens and from 6% to 11% for flexural specimens.

The statistical test used here is a comparison of two sample means, with the population variances for flawed and unflawed specimens assumed to be known and to be both equal to the calculated variance of the strengths of the entire group of unflawed specimens for a given core/test type combination.

The null hypothesis is **H_0**: $\mu_1 = \mu_2$.
The alternative hypothesis is **H_1**: $\mu_1 < \mu_2$.

The null hypothesis is rejected (that is, the population of flawed specimens with a given defect size is concluded to be weaker than the population of unflawed specimens) when:

$$z = \frac{\overline{x_2} - \overline{x_1}}{\sigma \cdot \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} > z_\alpha$$

where: n_1 and n_2 are the sample sizes (2 in most cases for these experiments, making the denominator of the above expression equal to 1) and σ is taken as the calculated standard deviation for all unflawed specimens of a given core type/test type combination.

At the 90% confidence level, $z_\alpha = 1.282$. Therefore, when the difference between the unflawed and flawed sample means is greater than $1.3 \cdot \sigma$, the conclusion that the defects in fact degraded the strength of the specimens is supported at the 90% confidence level.

Thus, for the experiments conducted, the average strength of a group of two flawed specimens must be at least $1.3 \cdot \sigma$ less than that of the control group of two unflawed specimens in order to support with 90% confidence the conclusion that the strength is actually degraded by the presence of the defect, σ being the standard deviation of strengths for unflawed specimens.

The unflawed specimen standard deviations for each core/test type combination are reported Tables 3 through 10 as fractions of the mean strengths of all unflawed specimens of that combination. Using these fractions, flawed samples are assumed to show actual weakening due to defects if the flawed sample strengths are degraded by more than the percentages of the unflawed sample strengths shown in Table 1.

Solid Tensile:	5.2%
Airex Tensile:	5.3%
Divinycell Tensile:	10.5%
Balsa Tensile:	5.9%
Solid Flexural:	7.7%
Airex Flexural:	14.6%
Divinycell Flexural:	14.8%
Balsa Flexural:	9.0%

Table 1 Minimum Significant Strength Deviations for Various Core-type/Test-type Combinations

8.2 Analysis of Experimental Results

This group comprises 70 individual experiments, each with either six or four specimens. For each experiment, a plot of strength (breaking load per unit width) is plotted against defect size For those experiments in which statistically significant degradations in strength were found in specimens with defects, those degradations are tabulated. The plots are presented in Appendix

ANALYSIS OF INDIVIDUAL EXPERIMENTAL RESULTS

Applying the statistical v\criteria presented in 8.1 to the individual experimental results, the following [core type/ test type/ defect size] combinations show apparent weakening due to the presence of defects.

EXP.	CORE	TEST	DEFECT	1"defect	2" defect
C4	Solid	Tensile	Delamination	-	6.4%
C5	Solid	Tensile	Cracks	11.6	14.5
E3	Airex	Tensile	Dry Fibers	5.6	12.7
E5	Airex	Tensile	Cracks	12.5	28.1
G5	Divinycell	Tensile	Cracks	11.1	19.6
J3	Balsa	Tensile	Dry Fibers	14.5	18.8
J5	Balsa	Tensile	Cracks	23.5	43.7
J6	Balsa	Tensile	Impact	6.1 (20)	16.3 (40)
P7	Balsa	Tensile	Core Filling	-	10.4
AC9	Airex	Tensile	Dirt	26.4% (full width)	
K1	Balsa	Flexural	Voids	-	14.4
K2	Balsa	Flexural	Uncured Resin	9.0	12.0
K3	Balsa	Flexural	Dry Fibers	-	9.9
K5	Balsa	Flexural	Cracks	22.1	31.6
K6	Balsa	Flexural	Impact	-	16.0 (40)
AH9	Balsa	Flexural	Dirt	9.0 (full width)	

Table 2 Experiments Showing Significant Strength Degradation Due to Defects

8.3 Conclusions

Very few of the defect type/core type combinations tested, either in flexural or tensile testing, showed definitive evidence of any significant strength reductions due to defects.

In some cases, the weakening effect of smaller defects is not statistically significant, while that of larger defects is. In the few cases in which the data indicated that the weakening effect of the smaller defects was statistically significant but that of larger defects was not, no effect is reported.

Balsa-cored specimens show more instances of significant weakening than either solid specimens or those having other core types. Since the variance in strength for unflawed Balsa-cored specimens is considerably smaller than for other cored types, a smaller difference between flawed and unflawed sample strengths becomes statistically significant for Balsa-cored specimens than for those having other cores. Balsa-cored tensile specimens showed a high incidence of failures at the core/core reinforcement interface, however, analysis of those failures shows no evidence that specimens which failed at the interface were weaker than those which failed elsewhere.

In general, tensile specimens show more instances of significant weakening as a result of defects than do flexural specimens. This is in part due to the generally lower variance in unflawed specimen strength for tensile specimens than for flexural specimens, which allows statistically valid conclusions about weakening to be made for smaller effects.

8.4 Technical Discussion - Failure Modes

A significant number of cored tensile specimens failed in the laminate skin over the interface between the core reinforcement and the core itself. This is not an unexpected result, since any discontinuity in the construction is expected to cause stress concentrations which make failure at the location of the discontinuity more likely. It should be noted that such a failure does not constitute a grip failure. (The results of specimens failing under the machine grips are disregarded). The core/core reinforcement interface was located well clear of the grip area on all tensile specimens tested.

This effect was most pronounced for balsa-cored specimens. 59% of all balsa-cored tensile specimens failed at the location of the core/core reinforcement interface, and 79% of all unflawed balsa-cored specimens failed there. When the specimens are traced back to the panels from which they were cut, it is apparent that certain particular core/core reinforcement joints in the original panels produced specimens which were very likely to fail at those joints.

Of the Divinycell-cored tensile specimens, 28% failed at the interface, and 43%of unflawed Divinycell-cored tensile specimens failed there. Again, particular panel locations produced a higher likelihood of failure.

Of the Airex-cored specimens, only 4% failed at the interface, and 7% of the unflawed specimens failed there.

A detailed analysis of interface failures shows no indication that coupons failing at the interface were weaker than those which failed in the cored area. Most experiments had two unflawed specimens and four flawed specimens. In many of these cases, the unflawed specimen showing the higher strength was the one which failed at the interface, while the weaker one failed in the core area. Thus, there is no justification for discounting the results of specimens which fail at the interface.

The list of statistically supportable conclusions shown in Table 2 is not affected if interface failures are discounted.

The tendency for unflawed cored tensile specimens to fail at the interface could mask subtle weakening effects of defects. In the pilot test program of this project, sample sizes were too small for slight effects to be discerned from random variations, however, in a full-scale test program with large sample sizes, slight effects might be detectable. If the coupon is clearly weaker over the interface than over the core, a specimen containing defect which only weakens the laminate slightly might still fail at the interface if the defect does not weaken the coupon as much as the interface does.

In conclusion, the use of core fillers is necessary to enable tensile testing of cored specimens, but the technique may mask subtle effects of defects.

9 UNFLAWED SPECIMEN PROPERTIES

One of the principal goals of this project was to quantify the variability in the experimentally determined strengths of unflawed specimens. Information about the expected variability of test results is essential to the design of further experiments.

For each of the 8 combinations of core type (4 including solid) and test type (2) the strength statistics for unflawed coupons were calculated. Within these groups, statistics for unflawed coupons of a given combination from each individual panel were also calculated.

The overall statistics are presented in Tables 3 through 10. The mean strengths, sample (n-1) standard deviations in strengths, and the standard deviations as a fraction of the means are tabulated. Where there are fewer than 3 specimens of a given combination from a given panel, only the mean is calculated, as standard deviation calculations for such small samples have little, if any, significance. The statistics between panels are calculated by computing the averages and sample standard deviations of the individual panel means.

9.1 Unflawed Specimen Data

SOLID TENSILE			
PANEL	MEAN	STD	STD/MEAN
5	19604	641	.033
6	18948	945	.050
23	18661		
overall	19282	778	.040
between panels	19071	483	.025

Table 3 Statistics for Solid Tensile Unflawed Specimens

SOLID FLEXURAL			
PANEL	MEAN	STD	STD/MEAN
1	441	11	.025
2	437	21	.048
6	439	16	.036
7	424	15	.035
19	474		
23	396		
overall	433	26	.059
between panels	435	25	.057

Table 4 Statistics for Solid Flexural Unflawed Specimens

AIREX Cored TENSILE			
PANEL	MEAN	STD	STD/MEAN
8	2717	118	.043
9	2733		
24	2851		
26	2815		
overall	2754	113	.041
between panels	2780	64	.023

Table 5 Statistics for Airex Cored Tensile Unflawed Specimens

AIREX Cored FLEXURAL			
PANEL	MEAN	STD	STD/MEAN
3	146	7	.048
4	134	10	.075
9	169		
10	150	10	.067
20	141		
24	127		
26	113		
overall	143	16	.112
between panels	140	18	.129

Table 6 Statistics for Airex Cored Flexural Unflawed Specimens

DIVINYCELL Cored TENSILE			
PANEL	MEAN	STD	STD/MEAN
11	2711	192	.071
12	2981		
24	3000		
26	2663		
overall	2784	225	.081
between panels	2839	176	.062

Table 7 Statistics for Divinycell Cored Tensile Unflawed Specimens

DIVINYCELL Cored FLEXURAL			
PANEL	MEAN	STD	STD/MEAN
12	151		
14	150	16	.107
21	157		
24	123		
26	129		
overall	145	17	.114
between panels	142	15	.106

Table 8 Statistics for Divinycell Cored Flexural Unflawed Specimens

BALSA Cored TENSILE			
PANEL	MEAN	STD	STD/MEAN
15	2676	99	.037
16	2905		
24	2722		
25	2764		
overall	2728	123	.045
between panels	2767	98	.035

Table 9 Statistics for Balsa Cored Tensile Unflawed Specimens

BALSA Cored FLEXURAL			
PANEL	MEAN	STD	STD/MEAN
16	202		
17	198	11	.056
22	226		
24	190		
25	195		
overall	201	14	.069
between panels	202	14	.069

Table 10 Statistics for Balsa Cored Flexural Unflawed Specimens

9.2 Analysis of Unflawed Specimen Data

9.2.1 The Statistical Properties of Unflawed Specimen Test Results

Most of the individual experiment groups included unflawed specimens in order that direct comparisons could be made of flawed and unflawed specimens originating in the same panel of laminate. These unflawed specimens can be divided into 8 groups defined by four core types (solid, Airex, Divinycell, and Balsa) and the two test types (tensile and flexural).

For each group, the mean and standard deviation of the scaled breaking load was computed. This information is valuable in the design of future experiments. If a certain level of confidence is required for the results of an experiment, an appropriate sample size must be set before the experiment begins. In order to select an appropriate sample size, one must have, in advance, a reasonable estimate of the expected variance of the quantity or quantities to be measured. While small samples can provide reasonably reliable estimates of mean quantities, larger samples are needed to provide good estimates of variances. The technique of pooling data for unflawed specimens over a number of experiments (and over specimens originating from many laminate panels) allows a reasonable estimate of variances in strength which can be used in further experimental design.

The data show that the standard deviations in strength for specimens from a given panel range from 2.5% to 10.7% of the individual panel mean values. (Approximately 68% of all specimens can be expected to have strengths within one standard deviation of the mean value).

9.2.2 Panel-to-Panel Variations in Mean Strength

In general, the variance in the mean strengths from one panel to another is of the same order as the variance of strengths between individual specimens from a given panel. Were there no significant variations in properties between panels, the variance of the panel means would be expected to be considerably lower than the variance for specimens within a panel. Thus, it is evident that there are real and significant, but not excessive, differences between the average properties of unflawed specimens from one panel to another. Many factors can contribute to these differences. Unavoidable variations in layup procedure due to the incorporation of different defect types in different panels, which affect the temperature history during the gel and early cure phases, and variations in the post-cure temperature history of panels are likely to be the significant factors in these differences.

Just as the expected variance in properties between specimens from a given panel is an important factor in determining the appropriate sample size for experiments involving specimens from a single panel, the additional variation in mean strengths between panels of otherwise identical makeup must be taken into account, in addition to the in-panel variability, in the design of any experiments which draw specimens from more than one panel.

For example, the experiments of this project which were intended to study defect size/panel width interactions were limited to single panels because of a lack of data about inter-panel variability. The resulting experiments were inconclusive, partly as a result of insufficient sample sizes. The design of further experiments into such interactive effects can utilize the information about intra-panel and inter-panel variability determined from this project, enabling appropriate sample sizes to be selected even though the large number of specimens required will likely have to come from more than one panel.

10 RECOMMENDATIONS FOR FURTHER TESTING

10.1 Type of Reinforcement

The use of narrow specimens to extrapolate the properties of larger panels creates a number of problems, many of which are discussed in the technical discussion above. Many of these narrowness and edge-related problems are aggravated by the use of angle-ply ($\pm 45°$) reinforcement, which results in stressed fibers ending at the specimen edges.

It is recommended that if rectangular test coupons are to be used in further testing, they be constructed only of 0/90° woven or unwoven reinforcement and mat. The use of mat does result in some stressed fibers having orientations other than 0° and 90°, but it is considered necessary in order to insure adequate bonding between layers of woven reinforcement and between core materials and woven reinforcement.

10.2 Test Specimen Size and Configuration

Because of the limitations of tensile-testing equipment, specimens considerably wider than the widest used in this project (3-7/8") are impractical. Limited experimental work has been done with cylindrical specimens, which allow off-axis reinforcement orientations to be used without any edge effects, since there are no free edges in the stressed area. However, both fabricating and testing a large number of cylindrical specimens would be both logistically and financially impractical. Accurately predicting the structural effects of defects in large, slightly curved hull panels by testing defective cylindrical specimens would be at least as difficult and uncertain as predicting defect effects by testing narrow flat specimens.

While tensile testing of large panels is expensive and difficult, flexural testing of large panels might be practical. A flexural test of a large circular panel supported by a ring smaller than and concentric with its edge and loaded by a smaller ring concentric with the center point or by a single nose at the center might solve a number of problems. The bending stress would vanish at the support ring and the free edge (the outer circumference of the panel) would be free of bending stress. (Longitudinal shear would still be present at the edge, and this might be a factor in the bending of cored specimens, however this effect would be no more significant in this case than it is for a narrow rectangular specimen.) The testing of laminates having angle-ply reinforcement would not present any problems in such a setup.

It is recommended that the use of circular flexure specimens, supported on a support ring approximately 30" in diameter and loaded by a circular ring loading nose, be considered for future testing.

A specimen of this size could be cut from a panel fabricated from 38" wide fabric, allowing suitable overhang past the support ring. Panel edge allowances would not be as important as for rectangular specimens cut from panels, since for a circular specimen, the material near the panel edges would not fall in the stressed area of the specimen. The fabrication cost per specimen would be increased considerably, since only two specimens would be obtained from a panel of about the same size as the panels which each produced 24 specimens for these experiments.

The circular flexure specimen would also allow much larger defects to be tested without any interactions between defects and the edges of the specimen.

The present rectangular flexure specimens are cut with their longitudinal axes aligned with the warp direction of the fiber reinforcement. The tests are conducted so that the principal stresses in the specimen are longitudinal. The mechanical properties, and the effects of defects, might vary considerably for specimens cut from panels with other reinforcement orientations. In a circular flexural specimen, stresses would be radial, and all orientations would, in effect, be stressed simultaneously, and failure will naturally occur along the axis of least strength. The defect production techniques developed for this project would all be readily adaptable to a circular specimen.

10.3 Tensile Testing vs. Flexural Testing

Most failures in substantially-built composite hulled boats are flexure-related. Tensile failures are generally confined to extremely light racing craft. While tensile testing may be useful in providing baseline material property information for unflawed specimens, flexural testing most closely reproduces the type of deformation that generally causes real-life failures of boat hulls. It is doubtful whether tensile testing of defective specimens yields any significant information. In addition, flexural testing is considerably less expensive and time-consuming to perform.

Tensile testing of cored specimens, while possible, introduces the problem of failures at the core/core reinforcement interface, discussed in section 8.4. This effect may mask the effects of defects on specimen strength.

<u>It is recommended that the effort devoted to tensile testing be limited in future test programs, that only unflawed specimens be tested in tension, and that the effort devoted to flexural testing be correspondingly increased.</u>

10.4 Defect Positioning

Defects in flexural specimens were placed only on the tension side of the bend in these experiments. However, a number of the defect types would be expected to have significant effects on the flexural properties of a laminate if placed on the compression side of the bend. In particular, defects like delamination, which have little effect on the tensile properties, and thus minimal effects when placed on the tensile fibers in a bend, would be expected to have significant effects on longitudinal compressive properties.

It is recommended that, in the screening stages of further experiments, all defect types be tested on both the tension side and the compression side of bends. (This means that one specimen will have one defect, either on the tension or the compression side. It does not mean that any specimen will have defects on both the tension and compression sides.) The four-point flexural test used in these experiments and specified for further experiments by the Test Procedure will allow a defect of significant size to be placed on the compression side of a flexural specimen without interference from the loading noses.

Edge effects might be more important with defects on the compression side than on the tension side of a flexure specimen, particularly with delaminations.

10.5 Wet Conditioning of Specimens

The mechanical properties of polyester/glass laminates are, in general, adversely affected by elevated moisture contents (Shen and Springer 1977), and of course, higher moisture contents are expected to occur in boat hulls. However, the purpose of this testing is not to determine absolute properties but to evaluate the effects of defects. There is no information available to indicate whether the weakening effect of a given type of defect is amplified by higher moisture contents or not. Because of this uncertainty, it might be advisable to include a study of moisture content effects in future phases of this project. Many of the early mechanical test results on glass/polyester hull materials are for materials conditioned wet for 30 days (Gibbs and Cox 1960). Wet conditioning would present a problem for cored laminates, however, since the cores would become saturated due to the exposure of the edges, a situation which is fairly unrealistic in a sound hull.

It is recommended that wet conditioning be considered in future testing.

10.6 Additional Defect Types

10.6.1 Secondary Bonding

While the test program developed during this project includes testing for the effects of local delaminations, the effects of secondary bonding between layers are not studied. Secondary bonding occurs when a layer of laminate is placed over an already-cured layer, and later delamination often occurs in a secondary bond. The secondary bond is an adhesive bond, rather than the three-dimensionally cross-linked chemically bonded resin structure that results from a continuous layup (a primary bond). The strength of a good secondary bond is considerably lower than a primary bond, and the quality of the secondary bond is greatly dependent upon the preparation which is given to the cured surface before the new layers are added.

The inclusion of secondary bonding as defect types might be a valuable addition to a defect test program. Several levels of secondary bonding could be simulated. No surface preparation or minimal abrasive preparation would result in poor secondary interlaminar bonding. Very thorough abrasive preparation of a rough surface, such as that resulting from the cured surface of coarse woven reinforcement materials, would result in a better secondary interlaminar bond, but would break the fiber continuity at the high spots, thus decreasing the strength of the abraded layer.

The secondary bond defect type would be relatively easy to implement since it would not be localized, and thus no careful positioning or variations in defect size would be required. The defect would cover an entire layer of the panel and of the coupons cut from that panel.

<u>It is recommended that secondary bonding, with at least two levels of surface preparation, be included as a defect type in future testing.</u>

10.6.2 Saturated Core

Water-saturated core material is a commonly encountered problem in cored fiberglass boats. This often occurs when the outer skin is damaged or when holes for the mounting of external hardware are not properly sealed. The water-saturated areas may extend a foot or more from the source of the water intrusion. Balsa-core is particularly susceptible to the problem, and its properties change considerably when wet.

<u>It is recommended that saturated core material be included as a defect type in future testing.</u>

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APPENDIX A Preliminary Test Results

The following are records of preliminary tensile and flexural tests which were conducted during the development of the initial testing and coupon production procedures. These tests resulted in the following decisions:

- End tabs were concluded to be unnecessary for tensile specimens of all types.

- Core reinforcement fillers were found to be necessary for the tensile testing of cored specimens. Acrylic sheet of the same thickness as the core material and replacing the core 5.5 inches from each end was finally settled upon as the most practical core filler material.

- A 4-point flexural test setup was selected, and a load nose diameter of 3 inches was decided upon.

- The estimated breaking loads and deflections were determined for both types of tests for both solid and cored specimens. This information was used to determine the final testing configuration, machine size requirements, and loading rates for both the pilot test program conducted as part of this project and for the full-scale testing program which was developed.

Records of Preliminary testing at AMTL

STAGE 1 Tested 1/8/92

1	Cored Layup No filler Tab failure - 25,000 lbf	5/16" tabs
2	Cored Layup No filler Tab Failure - 15,000 lbf	5/16" tabs
3	Cored Layup Plywood Filler Tab Failure - 20,000 lbf	5/16" tabs
4	Cored Layup Solid Glass Filler Good Break - 26,000 lbf	5/16" tabs

STAGE 2 tested 1/22/92

1	Solid layup Good break 50,000	1/8" Lexan tabs
2	Solid Layup Good break 59,000	No tabs
3	Airex Cored Layup 5" Plexiglas filler Tab failure - 18,120	1/8" Lexan tabs
4	Airex Cored Layup 5" Plexiglas Filler good break - 21,000	No tabs
5	Airex Cored Layup 6.5" Plexiglas Filler 1/8" long Lexan tabs Tab failure - 19,600	
6	Airex Cored - Flexure 3/4" dia. loading nose 1-pt load compression damage failure under loading nose 660 lbf max force major core shear failure	
7	Cored - Flexure 2.5" dia. loading nose 1-pt load Long. Compression failure under loading nose 680 lbf max. force.	

STAGE 3 tested 2/7/92
(all flexure tests - 2-point load - 2.5" dia noses 5" apart)

1 SOLID - flexure - no defects
bottomed out on fixture at 1630 lbs., no failure
preliminary failures began at 1150 lbs
max. deflection approx. 3.25"
retested with new setup, failed at 1860, 4" deflection.

2 SOLID - flexure - no defects
failed at 1940 lbs.

3 AIREX - flexure - no defects
tested with lexan pads under noses.
compression failure under l.h. support at 560 lbs.
no significant core shear.

4 AIREX - flexure - no defects
no pads.
compression failure under l.h. support at 450.
no significant core shear

5 BALSA - flexure - no defects
failed at 590 on compressive side between load noses.
initial failure at 500

6 BALSA - flexure - no defects
failed at 650 on compression side between noses
initial failure at 460

7 AIREX - flexure - 2" Delamination on compression side
failed at defect at 400 lbs.

8 BALSA - flexure - 2" Void on compression side
failed at defect at 410 lbs.
initial failure at 380 lbs.

APPENDIX B PILOT TEST PROGRAM DOCUMENTATION

B1 Panel Layout Plan

The following chart details the test coupon production for the pilot testing program. The position of each specimen, blocked by experiment, and randomized within experimental blocks, is shown.

TEST COUPON CODING

EXP NO.	SAMPLE NO.	TEST TYPE	WIDTH	CORE TYPE	FLAW SIZE
A1-B5	1-27	F	4,3,2	S,A,D,B	0,.5,1,1.5,2
C1-K5	1-6	T,F	4	S,A,D,B	0,1,2
L7-Q7	1-4	T,F	4	A,D,B	0,1,2
R8-Y8	1-2	T,F	4	S,A,D,B	3.9
AA9- AH9	1-4	T,F	4	S,A,D,B	3.9

TEST TYPE - T = Tensile
F = Flexural

WIDTH - 4 = 3.88"
3 = 3.07"
2 = 2.25"

CORE TYPE S = Solid
A = Airex
D = Divinycell
B = Balsa

DEFECTS (Defect Code is part of the experiment number)

Code	Abbrev.	TYPE
0	-	= Unflawed
1	V	= Voids
2	UR	= Uncured Resin
3	DF	= Dry Fibers
4	DL	= Delamination
5	CR	= Cracked Skin
6	ID	= Impact Damage (made as unflawed, damaged later)
7	CF	= Core Filling (Cored Specimens only)
8	L	= Lapped Reinforcement (Full width only)
9	D	= Dirt

DEFECT SIZE

0 = Unflawed
.5 = 1/2"
1 = 1"
1.5 = 1-1/2"
2 = 2"
3.9 = 3-7/8" (full width)

Impact Damage

0 = Unflawed
40 = 40 ft-lbf
80 = 80 ft-lbf

EXPERIMENT LIST

(Flaw Type contained in Experiment Number

EXP No.	Core Type	Test Type	Panel #	# Spec.	LAYUP	CUT	TEST
A1	S	F	1(1*)	27			
A5	S	F	2(2*)	27			
B1	A	F	3(3*)	27			
B5	A	F	4(4*)	27			
C1-4	S	T	5(5*)	4x6			
C5-6	S	T	6	2x6			
D5-6	S	F	6	2x6			
D1-4	S	F	7	4x6			
E1-4	A	T	8(8*)	4x6			
E5	A	T	9(26)	1x6			
E6	A	T	9	1x6			
F6	A	F	9	1x6			
F5	A	F	9(26)	1x6			
F1-4	A	F	10	4x6			
G1-4	D	T	11(11*)	4x6			
G5	D	T	12(26)	1x6			
G6	D	T	12	1x6			
H6	D	F	12	1x6			
H5	D	F	12(26)	1x6			
H1-4	D	F	14(14*)	4x6			
J1-4	B	T	15(15*)	4x6			
J5	B	T	16(25)	1x6			
J6	B	T	16	1x6			
K6	B	F	16	1x6			
K5	B	F	16(25)	1X6			
K1-4	B	F	17	4X6			
L7	A	T	18	1X4			
M7	A	F	18	1X4			
N7	D	T	18	1X4			
O7	D	F	18	1X4			

EXP No.	Core Type	Test Type	Panel #	# Spec.	LAYUP	CUT	TEST
P7	B	T	18	1X4			
Q7	B	F	18	1X4			
R8	S	T	19	1X2			
S8	S	F	19	1X2			
T8	A	T	20	1X2			
U8	A	F	20	1X2			
V8	D	T	21	1X2			
W8	D	F	21	1X2			
X8	B	T	22	1X2			
Y8	B	F	22	1X2			
AA9	S	T	23	1X4			
AB9	S	F	23	1X4			
AC9	A	T	24	1X4			
AD9	A	F	24	1X4			
AE9	D	T	24	1X4			
AF9	D	F	24	1X4			
AG9	B	T	24	1X4			
AH9	B	F	24	1X4			

SPECIMEN NUMBERING SCHEME

Experiments A1, A5, B1, B5 (4 exp, 27 spec each)

		Defect Size				
		0	.5"	1"	1.5"	2"
	2.25"	1	2, 3	4, 5	6, 7	8, 9
Width	3.125"	10	11, 12	13, 14	15, 16	17, 18
	3.875"	19	20, 21	22, 23	24, 25	26, 27

Experiments C - K, 1-6 (48 exp, 5 spec each)

Defect Size		
0	1"	2"
1,6	2, 3	4, 5

Experiments L7-Q7 (6 exp, 4 spec each)

Defect Size	
1"	2"
1, 2	3, 4

Experiments R8-Y8 (8 exp, 2 spec each)

Defect Size
3-7/8"
1, 2

Experiments AA9-AH9 (8 exp, 4 spec each)

Defect Size	
0	3-7/8"
1, 2	3, 4

PANEL 1(1*)   SOLID
EXP. A1   (All FLEXURAL) (All Defects VOIDS)

A1 - 1 - 0	A1 - 7 - 1.5	A1 - 6 - 1.5 2.25 wide
A1 - 17 - 2	A1 - 14 - 1	A1 - 18 - 2 3.06 wide
A1 - 26 - 2	A1 - 23 - 1	A1 - 22 - 1 3.88 wide
A1 - 8 - 2	A1 - 2 - .5	A1 - 4 - 1
A1 - 12 - .5	A1 - 11 - .5	A1 - 13 - 1
A1 - 27 - 2	A1 - 21 - .5	A1 - 25 - 1.5
A1 - 5 - 1	A1 - 9 - 2	A1 - 3 - .5
A1 - 15 - 1.5	A1 - 16 - 1.5	A1 - 10 - 0
A1 - 24 - 1.5	A1 - 20 - .5	A1 - 19 - 0

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/8 replace	4/26	5/10	5/13

PANEL 2(2*)   SOLID
EXP A5   (All FLEXURAL)   (All Defects CRACKS)

A5 - 9 - 2	A5 - 8 - 2	A5 - 7 - 1.5	2.25 wide
A5 - 18 - 2	A5 - 16 - 1.5	A5 - 15 - 1.5	3.06 wide
A5 - 19 - 0	A5 - 20 - .5	A5 - 27 - 2	3.88 wide
A5 - 1 - 0	A5 - 5 - 1	A5 - 4 - 1	
A5 - 13 - 1	A5 - 12 - .5	A5 - 10 - 0	
A5 - 24 - 1.5	A5 - 23 - 1	A5 - 26 - 2	
A5 - 2 - .5	A5 - 6 - 1.5	A5 - 3 - .5	
A5 - 17 - 2	A5 - 11 - .5	A5 - 14 - 1	
A5 - 25 - 1.5	A5 - 21 - .5	A5 - 22 - 1	

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/13 replace	4/25	5/10	5/13

PANEL 3(3*)   AIREX
EXP B1   (All FLEXURAL)   (All Defects VOIDS)

B1 - 4 - 1	B1 - 7 - 1.5	B1 - 1 - 0 2.25 wide
B1 - 10 - 0	B1 - 11 - .5	B1 - 14 - 1 3.06 wide
B1 - 27 - 2	B1 - 22 - 1	B1 - 19 - 0 3.88 wide
B1 - 9 - 2	B1 - 8 - 2	B1 - 2 - .5
B1 - 16 - 1.5	B1 - 18 - 2	B1 - 17 - 2
B1 - 26 - [illegible]	B1 - 25 - 1.5	B1 - 21 - .5
B1 - 3 - .5	B1 - 6 - 1.5	B1 - 5 - 1
B1 - 12 - .5	B1 - 13 - 1	B1 - 15 - 1.5
B1 - 24 - 1.5	B1 - 20 - .5	B1 - 23 - 1

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/11 replace	5/9	5/10	5/13

PANEL 4(4*) AIREX
EXP B5 (All FLEXURAL) (All Defects CRACKS)

B5 - 6 - 1.5	B5 - 4 - 1	B5 - 8 - 2 2.25 wide
B5 - 11 - .5	B5 - 16 - 1.5	B5 - 14 - 1 3.06 wide
B5 - 23 - 1	B5 - 24 - 1.5	B5 - 20 - .5 [illegible] wide
B5 - 7 - 1.5	B5 - 9 - 2	B5 - 1 - 0
B5 - 15 - 1.5	B5 - 17 - 2	B5 - 10 - 0
B5 - 27 - 2	B5 - 22 - 1	B5 - 21 - .5
B5 - 3 - .5	B5 - 2 - .5	B5 - 5 - 1
B5 - 13 - 1	B5 - 18 - 2	B5 - 12 - .5
B5 - 19 - 0	B5 - 26 - 2	B5 - 25 - 1.5

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/12 replace	4/18	5/10	5/13

PANEL 5(5*)   SOLID
EXP C1-C4   (All TENSILE)

C1 - 1 - 0	C1 - 4 - 2 - V	C2 - 6 - 0
C1 - 5 - 2 - V	C1 - 2 - 1 - V	C2 - 1 - 0
C1 - 6 - 0	C2 - 5 - 2 - UR	C2 - 4 - 2 - UR
C1 - 3 - 1 - V	C2 - 3 - 1 - UR	C2 - 2 - 1 - UR
C3 - 4 - 2 - DF	C4 - 4 - 2 - DL	C4 - 6 - 0
C3 - 1 - 0	C4 - 1 - 0	C4 - 3 - 1 - DL
C3 - 3 - 1 - DF	C3 - 2 - 1 - DF	C4 - 2 - 1 - DL
C3 - 5 - 2 - DF	C3 - 6 - 0	C4 - 5 - 2 - DL

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/2 replace	5/15	5/29	6/2

PANEL 6 SOLID
EXP C5-C6 (TENSILE), D5-D6 (FLEXURAL)

C5 - 4 - 2 - CR	T	C5 - 3 - 1 - CR	T	C6 - 6 - 0	T
C5 - 2 - 1 - CR	T	C5 - 6 - 0	T	C6 - 2 - 0	T
C5 - 5 - 2 - CR	T	C6 - 4 - 0	T	C6 - 3 - 0	T
C5 - 1 - 0	T	C6 - 1 - 0	T	C6 - 5 - 0	T
D5 - 3 - 1 - CR	F	D6 - 3 - 0	F	D6 - 4 - 0	F
D5 - 2 - 1 - CR	F	D6 - 2 - 0	F	D6 - 5 - 0	F
D5 - 6 - 0	F	D5 - 4 - 2 - CR	F	D6 - 6 - 0	F
D5 - 5 - 2 - CR	F	D5 - 1 - 0	F	D6 - 1 - 0	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
4/23	-	5/10	5/13

PANEL 7 SOLID
EXP D1-D4 (All FLEXURAL)

D1 - 3 - 1 - V	D1 - 5 - 2 - V	D2 - 1 - 0
D1 - 2 - 1 - V	D1 - 6 - 0	D2 - 3 - 1 - UR
D1 - 1 - 0	D2 - 4 - 2 - UR	D2 - 5 - 2 - UR
D1 - 4 - 2 - V	D2 - 2 - 1 - UR	D2 - 6 - 0
D3 - 5 - 2 - DF	D4 - 3 - 1 - DL	D4 - 6 - 0
D3 - 3 - 1 - DF	D4 - 5 - 2 - DL	D4 - 4 - 2 - DL
D3 - 4 - 2 - DF	D3 - 2 - 1 - DF	D4 - 2 - 1 - DL
D3 - 1 - 0	D3 - 6 - 0	D4 - 1 - 0

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
5/16	-	5/29	6/2

PANEL 8(8*) AIREX
EXP E1-E4 (All TENSILE)

E1 - 3 - 1 - V	E1 - 6 - 0	E2 - 5 - 2 - UR
E1 - 1 - 0	E1 - 4 - 2 - V	E2 - 2 - 1 - UR
E1 - 2 1 - V	E2 - 3 - 1 - UR	E2 - 6 - 0
E1 - 5 - 2 - V	E2 - 1 - 0	E2 - 4 - 2 - UR
E3 - 5 - 2 - DF	E4 - 4 - 2 - DL	E4 - 3 - 1 - DL
E3 - 4 - 2 - DF	E4 - 6 - 0	E4 - 2 - 1 - DL
E3 - 1 - 0	E3 - 2 - 1 - DF	E4 - 5 - 2 - DL
E3 - 6 - 0	E3 - 3 - 1 - DF	E4 - 1 - 0

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/3 replace	5/19	5/29	6/2

PANEL 9 AIREX **USE E6,F6; E5,F5 REPLACED IN PANEL #26**
EXP E5-E6 (TENSILE), F5-F6 (FLEXURAL)

E5 - 5 - 2 - CR	T	E5 - 2 - 1 - CR	T	E6 - 3 - 0	T
E5 - 1 - 0	T	E5 - 3 - 1 - CR	T	E6 - 1 - 0	T
E5 - 6 - 0	T	E6 - 5 - 0	T	E6 - 6 - 0	T
E5 - 4 - 2 - CR	T	E6 - 4 - 0	T	E6 - 2 - 0	T
F5 - 2 - 1 - CR	F	F6 - 2 - 0	F	F6 - 3 - 0	F
F5 - 5 - 2 - CR	F	F6 - 5 - 0	F	F6 - 6 - 0	F
F5 - 3 - 1 - CR	F	F5 - 6 - 0	F	F6 - 1 - 0	F
F5 - 4 - 2 - CR	F	F5 - 1 - 0	F	F6 - 4 - 0	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/14 redo part in 26	-	5/10	5/13

PANEL 10 AIREX
EXP F1-F4 (All FLEXURAL)

F1 - 5 - 2 - V	F1 - 3 - 1 - V	F2 - 4 - 2 - UR
F1 - 4 - 2 - V	F1 - 2 - 1 - V	F2 - 2 - 1 - UR
F1 - 6 - 0	F2 - 6 - 0	F2 - 3 - 1 - UR
F1 - 1 - 0	F2 - 1 - 0	F2 - 5 - 2 - UR
F3 - 4 - 2 - DF	F4 - 3 - 1 - DL	F4 - 2 - 1 - DL
F3 - 6 - 0	F4 - 4 - 2 - DL	F4 - 6 - 0
F3 - 2 - 1 - DF	F3 - 3 - 1 - DF	F4 - 1 - 0
F3 - 1 - 0	F3 - 5 - 2 - DF	F4 - 5 - 2 - DL

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/16		3/29	4/7

PANEL 11(11*) DIVINYCELL
EXP G1-G4 (All TENSILE)

G1 - 3 - 1 - V	G1 - 5 - 2 - V	G2 - 2 - 1 - UR
G1 - 4 - 2 - V	G1 - 1 - 0	G2 - 6 - 0
G1 - 2 - 1 - V	G2 - 3 - 1 - UR	G2 - 4 - 2 - UR
G1 - 6 - 0	G2 - 5 - 2 - UR	G2 - 1 - 0
G3 - 1 - 0	G4 - 4 - 2 - DL	G4 - 5 - 2 - DL
G3 - 5 - 2 - DF	G4 - 1 - 0	G4 - 6 - 0
G3 - 6 - 0	G3 - 2 - 1 - DF	G4 - 2 - 1 - DL
G3 - 4 - 2 - DF	G3 - 3 - 1 - DF	G4 - 3 - 1 - DL

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/4 replace	5/21	5/29	6/2

PANEL 12 DIVINYCELL **USE G6,H6; G5, H5 REPLACED IN PANEL #26**
EXP G5-G6 (TENSILE), H5-H6 (FLEXURAL)

G5 - 6 - 0	T	G5 - 1 - 0	T	G6 - 3 - 0	T
G5 - 4 - 2 - CR	T	G5 - 2 - 1 - CR	T	G6 - 1 - 0	T
G5 - 5 - 2 - CR	T	G6 - 5 - 0	T	G6 - 6 - 0	T
G5 - 3 - 1 - CR	T	G6 - 2 - 0	T	G6 - 4 - 0	T
H5 - 5 - 2 - CR	F	H6 - 3 - 0	F	H6 - 4 - 0	F
H5 - 4 - 2 - CR	F	H6 - 2 - 0	F	H6 - 5 - 0	F
H5 - 6 - 0	F	H5 - 3 - 1 - CR	F	H6 - 1 - 0	F
H5 - 1 - 0	F	H5 - 2 - 1 - CR	F	H6 - 6 - 0	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/15 redo part in 26		5/10	5/13

PANEL 14(14*) DIVINYCELL CORE
EXP H1-H4 (All FLEXURAL)

H1 - 3 - 1 - V	H1 - 2 - 1 - V	H2 - 1 - 0
H1 - 1 - 0	H1 - 6 - 0	H2 - 5 - 2 - UR
H1 - 5 - 2 - V	H2 - 4 - 2 - UR	H2 - 2 - 1 - UR
H1 - 4 - 2 - V	H2 - 3 - 1 - UR	H2 - 6 - 0
H3 - 4 - 2 - DF	H4 - 4 - 2 - DL	H4 - 6 - 0
H3 - 2 - 1 - DF	H4 - 1 - 0	H4 - 2 - 1 - DL
H3 - 5 - 2 - DF	H3 - 1 - 0	H4 - 5 - 2 - DL
H3 - 6 - 0	H3 - 3 - 1 - DF	H4 - 3 - 1 - DL

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/10 replace	4/22	5/10	5/13

PANEL 15(15*) BALSA CORE
EXP J1-J4 (All TENSILE)

J1 - 1 - 0	J1 - 6 - 0	J2 - 1 - 0
J1 - 2 - 1 - V	J1 - 4 - 2 - V	J2 - 3 - 1 - UR
J1 - 3 - 1 - V	J2 - 6 - 0	J2 - 5 - 2 - UR
J1 - 5 - 2 - V	J2 - 2 - 1 - UR	J2 - 4 - 2 - UR
J3 - 5 - 2 - DF	J4 - 5 - 2 - DL	J4 - 3 - 1 - DL
J3 - 6 - 0	J4 - 4 - 2 - DL	J4 - 6 - 0
J3 - 1 - 0	J3 - 2 - 1 - DF	J4 - 2 - 1 - DL
J3 - 4 - 2 - DF	J3 - 3 - 1 - DF	J4 - 1 - 0

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/9 replace	5/22	5/29	6/2

PANEL 16 BALSA CORE **USE J6, K6; J5, K5 REPLACED IN PANEL #25**
EXP J5-J6 (TENSILE), K5-K6 (FLEXURAL)

J5 - 4 - 2 - CR	T	J5 - 3 - 1 - CR	T	J6 - 5 - 0	T
J5 - 5 - 2 - CR	T	J5 - 2 - 1 - CR	T	J6 - 3 - 0	T
J5 - 6 - 0	T	J6 - 1 - 0	T	J6 - 6 - 0	T
J5 - 1 - 0	T	J6 - 4 - 0	T	J6 - 2 - 0	T
K5 - 6 - 0	F	K6 - 5 - 0	F	K5 - 1 - 0	F
K5 - 4 - 2 - CR	F	K6 - 6 - 0	F	K6 - 4 - 0	F
K5 - 2 - 1 - CR	F	K5 - 5 - 2 - CR	F	K6 - 3 - 0	F
K5 - 1 - 0	F	K5 - 3 - 1 - CR	F	K6 - 2 - 0	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/15 redo part in 25	-	5/10	5/13

PANEL 17 BALSA CORE
EXP K1-K4 (All FLEXURAL)

K1 - 1 - 0	K1 - 6 - 0	K2 - 1 - 0
K1 - 3 - 1 - V	K1 - 2 - 1 - V	K2 - 6 - 0
K1 - 5 - 2 - V	K2 - 3 - 1 - UR	K2 - 2 - 1 - UR
K1 - 4 - 2 - V	K2 - 4 - 2 - UR	K2 - 5 - 2 - UR
K3 - 1 - 0	K4 - 4 - 2 - DL	K4 - 5 - 2 - DL
K3 - 3 - 1 - DF	K4 - 1 - 0	K4 - 2 - 1 - DL
K3 - 4 - 2 - DF	K3 - 5 - 2 - DF	K4 - 3 - 1 - DL
K3 - 2 - 1 - DF	K3 - 6 - 0	K4 - 6 - 0

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/17		3/29	4/7

PANEL 18 AIREX, DIVINYCELL, BALSA CORES
EXP L7, M7, N7, O7, P7, Q7 (All Defects CORE FILLING)

L7 - 4 - 2	T	N7 - 3 - 2	T	P7 - 1 - 1	T
L7 - 2 - 1	T	N7 - 4 - 2	T	P7 - 4 - 2	T
L7 - 1 - 1	T	N7 - 1 - 1	T	P7 - 2 - 1	T
L7 - 3 - 2	T	N7 - 2 - 1	T	P7 - 3 - 2	T
M7 - 4 - 2	F	O7 - 2 - 1	F	Q7 - 2 - 1	F
M7 - 3 - 2	F	O7 - 4 - 2	F	Q7 - 3 - 2	F
M7 - 2 - 1	F	O7 - 3 - 2	F	Q7 - 4 - 2	F
M7 - 1 - 1	F	O7 - 1 - 1	F	Q7 - 1 - 1	F
AIREX		DIVINYCELL		BALSA	

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/18		3/29	4/7

PANEL 19 SOLID CORE
EXP R8,S8 (Full-width LAPPED REINFORCEMENT)

R8 - 1	T
R8 - 2	T
S8 - 1	F
S8 - 2	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/19		3/29	4/7

PANEL 20 AIREX CORE
EXP T8, U8 (Full-width LAPPED REINFORCEMENT)

T8 - 1	T
T8 - 2	T
U8 - 1	F
U8 - 2	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/19		3/29	4/7

PANEL 21 DIVINYCELL CORE
EXP V8, W8 (Full-width LAPPED REINFORCEMENT)

V8 - 1	T
V8 - 2	T
W8 - 1	F
W8 - 2	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/19		3/29	4/7

PANEL 22 Balsa Core
EXP X8, Y8 (Full-width LAPPED REINFORCEMENT)

X8 - 1	T
X8 - 2	T
Y8 - 1	F
Y8 - 2	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
2/19		3/29	4/7

PANEL 23 SOLID
EXP AA9, AB9 (DIRT)

AA9 - 1 - 0	T	AA9 - 3 - 4 - D	T
AA9 - 2 - 0	T	AA9 - 4 - 4 - D	T
AB9 - 2 - 0	F	AB9 - 4 - 4 - D	F
AB9 - 1 - 0	F	AB9 - 3 - 4 - D	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
5/18	-	5/29	6/2

PANEL 24 Airex/Divinycell/Balsa (TENSILE/FLEXURAL)
EXP AC9 - AH9 (DIRT)

AC9 - 1 - 0	T	AE9 - 1 - 0	T	AG9 - 1 - 0	T
AC9 - 2 - 0	T	AE9 - 2 - 0	T	AG9 - 2 - 0	T
AC9 - 3 - 4 - D	T	AE9 - 3 - 4 - D	T	AG9 - 3 - 4 - D	T
AC9 - 4 - 4 - D	T	AE9 - 4 - 4 - D	T	AG9 - 4 - 4 - D	T
AD9 - 4 - 4 - D	F	AF9 - 4 - 4 - D	F	AH9 - 4 - 4 - D	F
AD9 - 3 - 4 - D	F	AF9 - 3 - 4 - D	F	AH9 - 3 - 4 - D	F
AD9 - 2 - 0	F	AF9 - 2 - 0	F	AH9 - 2 - 0	F
AD9 - 1 - 0	F	AF9 - 1 - 0	F	AH9 - 1 - 0	F
AIREX		DIVINYCELL		BALSA	

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
5/23	-	5/29	6/2

PANEL 25 (REPLACES J5 AND K5 FROM PANEL 16)
EXP J5, K5 (BALSA, T/F, all CRACKS)

J5 - 4 - 2 - CR	T	K5 - 6 - 0	F
J5 - 5 - 2 - CR	T	K5 - 4 - 2 - CR	F
J5 - 6 - 0	T	K5 - 2 - 1 - CR	F
J5 - 1 - 0	T	K5 - 1 - 0	F
J5 - 3 - 1 - CR	T	K5 - 5 - 2 - CR	F
J5 - 2 - 1 - CR	T	K5 - 3 - 1 - CR	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
5/25	-	5/29	6/2

PANEL 26 (REPLACES E5, F5 FROM PANEL 9 AND G5, H5 FROM PANEL 16)
EXP E5, F5 (Airex T/F, cracks)   G5, H5 (Divinycell T/F, cracks)

E5 - 5 - 2 - CR	Airex	T	E5 - 2 - 1 - CR	Airex	T	G5 - 6 - 0	DIV	T
E5 - 1 - 0	Airex	T	E5 - 3 - 1 - CR	Airex	T	G5 - 4 - 2 - CR	DIV	T
E5 - 6 - 0	Airex	T	G5 - 1 - 0	DIV	T	G5 - 5 - 2 - CR	DIV	T
E5 - 4 - 2 - CR	Airex	T	G5 - 2 - 1 - CR	DIV	T	G5 - 3 - 1 - CR	DIV	T
F5 - 2 - 1 - CR	Airex	F	H5 - 3 - 1 - CR	DIV	F	H5 - 5 - 2 - CR	DIV	F
F5 - 5 - 2 - CR	Airex	F	H5 - 2 - 1 - CR	DIV	F	H5 - 4 - 2 - CR	DIV	F
F5 - 3 - 1 - CR	Airex	F	F5 - 6 - 0	Airex	F	H5 - 6 - 0	DIV	F
F5 - 4 - 2 - CR	Airex	F	F5 - 1 - 0	Airex	F	H5 - 1 - 0	DIV	F

INITIAL LAYUP	REPLACEMENT LAYUP	CUT	DELIV. FOR TEST
5/24	-	5/29	6/2

B2 Randomization Chart

This chart specifies the positions of each test specimen within the panel blocks allotted for the specimens making up each particular experiment.

Numbers in the Left Columns are Specimen Numbers as per the specimen numbering scheme. Corresponding numbers in the Right Columns are Panel Block Positions.

Fig. 1 shows the allocation of panel blocks and position numbers within blocks for experiments A and B. Fig. 2 shows allocations for Experiments C through K. Fig. 3 shows allocations for L through Q. Experiments R through Y have only two (identical) specimens per experiment, so no randomization of position within blocks is possible for these experiments.

1	4	7
1	4	7
1	4	7
2	5	8
2	5	8
2	5	8
3	6	9
3	6	9
3	6	9

SPECIMEN POSITIONING
EXP. A -B

Fig. 1

1	5	1
2	6	2
3	5	3
4	6	4
4	6	4
3	5	3
2	6	2
1	5	1

SPECIMEN POSITIONING
EXP C - K

Fig. 2

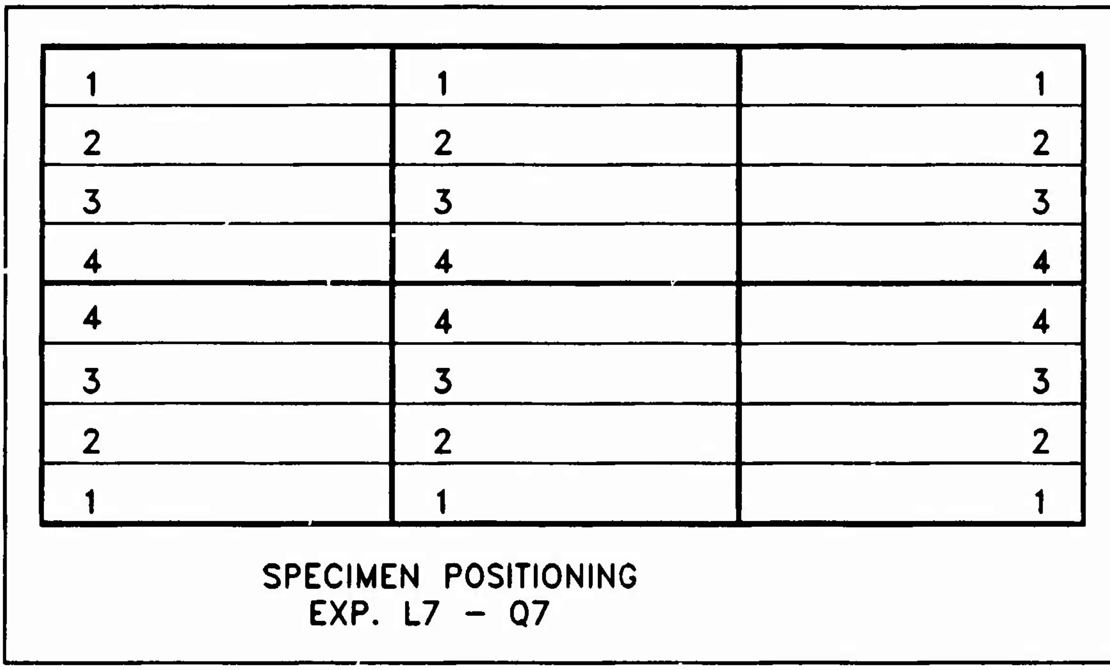

1 1 1
2 2 2
3 3 3
4 4 4
4 4 4
3 3 3
2 2 2
1 1 1
SPECIMEN POSITIONING
EXP. L7 - Q7

Fig. 3

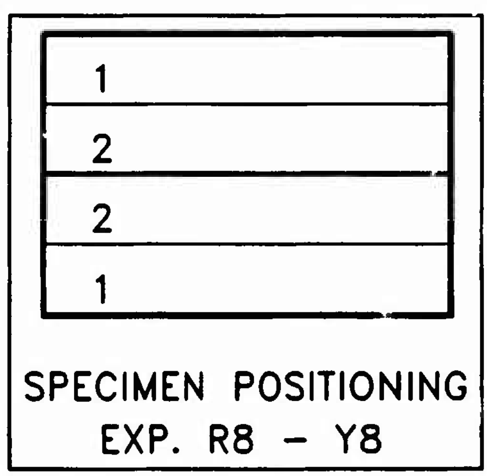

1
2
2
1
SPECIMEN POSITIONING
EXP. R8 - Y8

Fig. 4

Randomization

For each experiment, the left column contains the numbers of the panel positions within the panel blocks allocated for that experiment, the right column contains the specimen number allocated to that position under the randomization scheme.

The random number sequences were computed with the attached computer program.

EXPERIMENT A1 (Panel 1)

2.25"		3.125"		3.875"	
1	1	1	8	1	8
2	8	2	3	2	9
3	5	3	6	3	6
4	7	4	5	4	5
5	2	5	2	5	3
6	9	6	7	6	2
7	6	7	9	7	4
8	4	8	4	8	7
9	3	9	1	9	1

EXPERIMENT A5 (Panel 2)

2.25"		3.125"		3.875"	
1	9	1	9	1	1
2	1	2	4	2	6
3	2	3	8	3	7
4	8	4	7	4	2
5	5	5	3	5	5
6	6	6	2	6	3
7	7	7	6	7	9
8	4	8	1	8	8
9	3	9	5	9	4

EXPERIMENT B1 (panel 3)

2.25"		3.125"		3.875"	
1	4	1	1	1	9
2	9	2	7	2	8
3	3	3	3	3	6
4	7	4	2	4	4
5	8	5	9	5	7
6	6	6	4	6	2
7	1	7	5	7	1
8	2	8	8	8	3
9	5	9	6	9	5

EXPERIMENT B5 (panel 4)

2.25"		3.125"		3.875"	
1	6	1	2	1	5
2	7	2	6	2	9
3	3	3	4	3	1
4	4	4	7	4	6
5	9	5	8	5	4
6	2	6	9	6	8
7	8	7	5	7	2
8	1	8	1	8	3
9	5	9	3	9	7

EXPERIMENTS C1-C6 (Panels 5 & 6)

1		2		3		4		5		6	
1	1	1	6	1	5	1	5	1	4	1	6
2	5	2	1	2	3	2	2	2	2	2	2
3	6	3	4	3	1	3	3	3	5	3	3
4	3	4	2	4	4	4	6	4	1	4	5
5	4	5	5	5	6	5	1	5	3	5	4
6	2	6	3	6	2	6	4	6	6	6	1

EXPERIMENTS D1-D6 (Panels 7 & 6)

1		2		3		4		5		6	
1	3	1	1	1	1	1	1	1	5	1	1
2	2	2	3	2	4	2	2	2	6	2	6
3	1	3	5	3	3	3	4	3	2	3	5
4	4	4	6	4	5	4	6	4	3	4	4
5	5	5	4	5	6	5	5	5	1	5	2
6	6	6	2	6	2	6	3	6	4	6	3

EXPERIMENTS E1-E6 (Panels 8 & 9)

1		2		3		4		5		6	
1	3	1	5	1	6	1	1	1	5	1	3
2	1	2	2	2	1	2	5	2	1	2	1
3	2	3	6	3	4	3	2	3	6	3	6
4	5	4	4	4	5	4	3	4	4	4	2
5	6	5	3	5	3	5	6	5	2	5	5
6	4	6	1	6	2	6	4	6	3	6	4

EXPERIMENTS F1-F6 (Panels 10 & 9)

1		2		3		4		5		6	
1	5	1	4	1	1	1	5	1	4	1	4
2	4	2	2	2	2	2	1	2	3	2	1
3	6	3	3	3	6	3	6	3	5	3	6
4	1	4	5	4	4	4	2	4	2	4	3
5	3	5	6	5	5	5	4	5	1	5	5
6	2	6	1	6	3	6	3	6	6	6	2

EXPERIMENTS G1-G6 (Panels 11 & 12)

1		2		3		4		5		6	
1	3	1	2	1	4	1	3	1	6	1	3
2	4	2	6	2	6	2	2	2	4	2	1
3	2	3	4	3	5	3	6	3	5	3	6
4	6	4	1	4	1	4	5	4	3	4	4
5	5	5	3	5	3	5	1	5	1	5	5
6	1	6	5	6	2	6	4	6	2	6	2

EXPERIMENTS H1-H6 (Panels 14 & 12)

1		2		3		4		5		6	
1	3	1	1	1	6	1	3	1	1	1	6
2	1	2	5	2	5	2	5	2	6	2	1
3	5	3	2	3	2	3	2	3	4	3	5
4	4	4	6	4	4	4	6	4	5	4	4
5	2	5	4	5	3	5	1	5	2	5	2
6	6	6	3	6	1	6	4	6	3	6	3

EXPERIMENTS J1-J6 (Panels 15 & 16)

1		2		3		4		5		6	
1	1	1	1	1	4	1	1	1	4	1	5
2	2	2	3	2	1	2	2	2	5	2	3
3	3	3	5	3	6	3	6	3	6	3	6
4	5	4	4	4	5	4	3	4	1	4	2
5	6	5	6	5	3	5	4	5	3	5	4
6	4	6	2	6	2	6	5	6	2	6	1

EXPERIMENTS K1-K6 (Panels 17 & 16)

1		2		3		4		5		6	
1	1	1	1	1	2	1	6	1	1	1	2
2	3	2	6	2	4	2	3	2	2	2	3
3	5	3	2	3	3	3	2	3	4	3	4
4	4	4	5	4	1	4	5	4	6	4	1
5	6	5	3	5	6	5	1	5	3	5	6
6	2	6	4	6	5	6	4	6	5	6	5

EXPERIMENTS L7-Q7 (Panel 18)

L7		M7		N7		O7		P7		Q7	
1	4	1	1	1	3	1	1	1	1	1	1
2	2	2	2	2	4	2	3	2	4	2	4
3	1	3	3	3	1	3	4	3	2	3	3
4	3	4	4	4	2	4	2	4	3	4	2

(Experiments R8 - Y8 Require no randomization)

B3 Randomization Program

The following BASIC computer program was written to assist the assignment of test specimens to randomized positions on the panels from which they are cut. The program generates a sequence of random integers of desired length which are used to correlate specimen numbers to predetermined numbered panel positions. the output is written to an ASCII data file, the name of which is selected by the user. The random number generator is seeded from a PC's internal clock, insuring that each sequence will be different.

```
'Random Number Generator  1/9/92
color 0,7
cls
print "                    RANDOM INTEGER GENERATOR"
print
print "  Generates Indexed Random Integers from 1 to N Without Duplication"
print
print "  Output Available to Screen, Printer and/or ASCII File"
print
print "  If ASCII file output is desired, run this program from the "
print "   directory in which you want the file stored.  The file will"
print "   be named ID.RND, where ID is the Identifier of the Random"
print "   Integer sequence (for which the program prompts)."
print: input "          (Paused - press any key to continue) - ",DUMMY$
STARTPROGRAM:
cls
input "  Length of Random Integer Sequence - ",N
input "  Identifier - ",ID$
DIM X(N+1)
RANDOMIZE TIMER
for j = 1 to N
      BEGINLOOP:
      x(j) = INT(RND * N) + 1
      for i = 1 to j-1
            if x(i) = x(j) then goto BEGINLOOP
      next i
next j
cls
print ID$
k = 0
for j = 1 to N
      print using "####   ####";j;x(j)
      k = k+1
      if k=22 then input " paused - press any key to continue - ",DUMMY$:_
      k=0:cls:print ID$
next j
input " send sequence to printer? (1/0) - ",PRT
if PRT = 1 then gosub PRINTSEQUENCE
input " send sequence to ASCII file? (1/0) -",ASCFIL
if ASCFIL = 1 then OUTFILE$ = ID$ + ".RND"
if ASCFIL = 1 then gosub WRTFIL
input "Another series? (1/0) - ",RPT
if RPT = 1 then erase x: goto STARTPROGRAM
END
```

```
'SUBROUTINES FOLLOW:

PRINTSEQUENCE:
      lprint "Sequence of ";N;" Random Integers":lprint
      lprint ID$:lprint
      for j = 1 to N
            lprint using "####    ####";j;x(j)
      next j
      lprint:lprint:lprint
RETURN


WRTFIL:              ' Writes an ASCII data file
open OUTFILE$ for output as #1
for j = 1 to N
      if N>1 and N<10 then print #1, using "#   #";j; x(j)
      if N>9 and N<100 then print #1, using "##   ##";j;x(j)
next j
close #1
RETURN
```

B4 Primary Material Source Information

The following information documents the materials used in the production of test specimens for the pilot test program.

RESIN

Mfg. Cargill Corp. Atlanta GA
Source Boatex Fiberglass Inc. Natick MA

#85-8533 Unsaturated Fire Retardant Polyester Resin
55 gal. steel drums

Drum #1 Lot # 112007 mfg. dated 12/06/91
purchased 1/13/92 invoice 38816
Drum #2 Lot # 112007 mfg. dated 12/06/91
purchased 2/19/92 invoice 39438

INITIATOR (Catalyst)

Mfg. The NORAC COMPANY Inc. Azusa CA
Source R.P. Associates Bristol RI

MEKP-9H 9% Active Oxygen Methyl ethyl ketone peroxide solution
1 gal. polyethylene jugs

Jug #1 Lot # 103762
purchased 1/9/92 invoice 60057/72476
Jug #2 Lot # 012642
purchased 3/17/92 invoice 60057/74838

CATALYZATION OF RESIN

For **Cargill 85-8533 Resin** (10.5 lbs/gallon) and NORAC MEKP-9H initiator (catalyst),the required catalyst volume ratio to achieve a weight ratio of 1% is:

23 cc (22.7cc exactly) per 2 quarts of resin

The catalyst can be measured to about ±2 cc, which gives a range of 0.91% to 1.09%.

TEMPERATURES

CURING TEMPERATURE must be **72±5°F** for 24 hours after layup.

LAYUP TEMPERATURE will have to be adjusted to suit the gel time of the resin at the required catalyst ratio. Avoid laying up panels in when the relative humidity in the shop exceeds 70%.

PVC FOAM CORE Material

Mfg. AIREX AG Switzerland
Dist.
Torin Inc. Waldwick NJ
Source R.P. Associates Bristol RI

R 63.80 (Replaces R62.80) Contour 12mm
1150x500 mm sheets

Box #1 039 28257 Order A616
purchased 1/9/92 invoice 60057/72476
Box #2 027 28257 Order A616
purchased 3/17/92 invoice 60057/74838

Balsa Core Material

Mfg. BALTEK Inc.
Source R.P. Associates Natick MA

AL-600 1/2" Balsa Core diced w/attached glass scrim

Box #1 purchased 1/9/92 invoice 60057/72476

PVC FOAM CORE Material

Mfg. DIAB-Barracuda
Source Boatex Fiberglass Company, Inc. Natick MA

H80 1/2" GSN Contoured DIVINYCELL w/attached glass scrim

Box #1 purchased 1/7/92 invoice 38747

10 Oz. Fiberglass Cloth

Mfg. Hexcel Trevarno Seguin TX
Source R.P. Associates Bristol RI

S2156 7500-38-F16 (part no., style-width-finish)

Roll #1 Loom/Roll no. 169L63251-012A
Order No. 2156F3221 129yds. mfg. dated 12/15/91
purchased 1/9/92 invoice 60057/72476

24 Oz. Fiberglass Woven Roving

Mfg. Vetrotex CertainTeed Wichita Falls TX
Source R.P. Associates Bristol RI

324-3B 24 oz. 38"
Prod. code 13BN324380

Roll #1 164 lb. mfg. dated 11/8/91
purchased 1/9/92 invoice 60057/72476
Roll #2 163 lb. mfg. dated 11/8/91
purchased 3/18/92 invoice 60057/74838

1.5 oz. Chopped-Strand Fiberglass Mat.

Mfg. Vetrotex CertainTeed Wichita Falls TX
Source R.P. Associates Bristol RI

M127 1-1/2 oz. 38"
Prod. code GB2L127538

Roll #1 84 lb. mfg. dated 11/7/91
purchased 1/9/92
Roll #2 86 lb. mfg. dated 3/10/92
purchased 3/17/92

0.75 oz. Chopped-Strand Fiberglass Mat

Mfg. Vetrotex CertainTeed Wichita Falls TX
Source R. P. Associates Bristol R.I.

M113 3/4 oz. 38"
Prod. Code GB2L113538

Roll #1 101 lb. mfg. dated 9/17/91
purchased 1/9/92

DBM-1708 Biaxial Reinforcement

Mfg. Hexcel Trevarno Seguin TX
Source R.P. Associates Bristol RI

part no. N300707
Mfg. description DBM1708-38.00

Roll #1 mfg. work order 353581008
mfg. dated 9/19/91 125 lb.
purchased 1/9/92
Roll #2 mfg. work order 353581008
mfg. dated 9/19/91 120 lb.
purchased 3/18/92

B5 Panel Fabrication, Inspection, and Test Records

The following table is a prototype of the records kept during panel production. The actual records are handwritten in a laboratory notebook which was kept in the fabrication facility. This notebook was delivered to the COTR at the time of submission of this report.

Environmental conditions in the layup facility were measured by a digital thermometer/hygrometer with and minimum/maximum recording capability for both temperature and humidity.

DATE	PANEL #	LAYUP TYPE TEST TYPE

LAYUP AND CURE RECORD

	TIME	TEMP	HUMIDITY
LAYUP START			
LAYUP END			
CURE PERIOD START			
CURE MAX	XXXXXXXXXXXX XXXX		
CURE MIN	XXXXXXXXXXXX XXXX		
CURE PERIOD END			

RESIN BATCH SIZE	
CATALYST AMOUNT	
# OF BATCHES	
RESIN SOURCE	
CATALYST SOURCE	

COMMENTS (glass roll changes, resin drum or catalyst jug changes, etc.)	

SIGNATURE OF LAYUP TECHNICIAN

date / time

Panel Fabrication and Inspection Record

Panel no.	Layup Date	Panel Type	Size	Insp. Date	Comments and Insp. results	Made	Cut	Test Batch
Panels in this block from first batch 2/2 - 2/13 to be remade per agreement with CG.								
5	2/2	Solid T	Full	2/3	OK - adjust layup temp spec to 60F to avoid heat damage	X		
8	2/3	Airex T	Full	2/3* 2/6	OK - abandon use of pressure bag, use 60F for cored layup also.	X		
11	2/4	Div'cl T	Full	2/6	OK	X		
1	2/8	Solid F	Full	2/10	OK	X		
15	2/9	Balsa T	Full	2/10	OK	X		
14	2/10	Div'cl F	Full	2/10* 2/12	OK	X		
3	2/11	Airex F	Full	2/18	OK	X		
4	2/12	Airex F	Full	2/18	cracks wrong - remake whole panel	X		
2	2/13	Solid F	Full	2/18	cracks wrong - remake whole panel	X		
Panels in this block from second batch 2/14-2/19 are OK								
10	2/16	Airex F	Full	2/18	OK	X	4/3	1
17	2/17	Balsa F	Full	2/18	OK	X	4/3	1
18	2/18	A/D/B T/F	Full	2/18* 2/19	OK	X	4/3	1
19	2/19	Solid T/F	1/6	2/19 2/21	OK	X	4/3	1
20	2/19	Airex T/F	1/6	2/19 2/21	OK	X	4/3	1
21	2/19	Div'cl T/F	1/6	2/19* 2/21	OK	X	4/3	1
22	2/19	Balsa T/F	1/6	2/19* 2/21	OK	X	4/3	1

Panel no.	Layup Date	Panel Type	Size	Insp. Date	Comments and Insp. results	Made	Cut	Test Batch
Panels in this block from second batch; impact specimens OK, crack specimens to be remade as parts of panels 25 and 26.								
9	2/14	Airex T/F	Full	2/18	cracks wrong - remake 1/2 of panel	X	5/10	2
12	2/15	Div'cl T/F	Full	2/18	cracks wrong - remake 1/2 of panel	X	5/10	2
16	2/15	Balsa T/F	Full	2/18	cracks wrong - remake 1/2 of panel	X	5/10	2
Panels in this block to be made in third batch starting 4/18								
4*	4/18	Airex F	Full	4/18*		X	5/10	2
6	4/23	Solid T/F	Full	4/26			5/10	2
8*	5/19	Airex T	Full	5/21			5/29	3
11*	5/21	Div'cl T	Full	5/21*, 5/24			5/29	3
14*	4/22	Div'cl F	Full	4/22*, 4/25			5/10	2
15*	5/22	Balsa T	Full	5/24			5/29	3
1*	4/26	Solid F	Full	4/29			5/10	2
2*	4/25	Solid F	Full	4/25*, 4/29			5/10	2
3*	5/9	Airex F	Full	5/11			5/10	2
5*	5/15	Solid T	Full	5/21			5/29	3
7	5/16	Solid F	Full	5/21			5/29	3
23	5/18	Solid T/F	1/3	5/21			5/29	3
24	5/23	A/D/B T/F	Full	5/24			5/29	3
25	5/25	Balsa T/F	1/2	5/29			5/29	3
26	5/24	A/D T/F	Full	5/24*, 5/29			5/29	3

* after inspection date indicates inspection while layup was in progress

Panel Type Codes:

Solid	=	Solid layup
Airex	=	Airex cored
Div'cl	=	Divinycell cored
Balsa	=	Balsa Cored
A/D/B, etc,	=	Multiple core types in one panel
T	=	Tensile specimens (cored tensile specimens have plexiglass core fillers)
F	=	Flexural specimens
T/F	=	Tensile and Flexural specimens in the same panel

Test Batches

1. Delivered to AMTL 4/7/92
2. Delivered to AMTL 5/13/92
3. Delivered to AMTL 6/2/92

Test Records BATCH 1
Delivered to AMTL 4/7/92

EXP. No.	PANEL	TEST	CORE	DEFECT	# SPEC.	
F1	10	F	A	V	1-6	
F2	10	F	A	UR	1-6	
F3	10	F	A	DF	1-6	
F4	10	F	A	DL	1-6	
K1	17	F	B	V	1-6	
K2	17	F	B	UR	1-6	
K3	17	F	B	DF	1-6	
K4	17	F	B	DL	1-6	
L7	18	T	A	CF	1-4	
N7	18	T	D	CF	1-4	
P7	18	T	B	CF	1-4	
M7	18	F	A	CF	1-4	
O7	18	F	D	CF	1-4	
Q7	18	F	B	CF	1-4	
R8	19	T	S	L	1-2	
S8	19	F	S	L	1-2	
T8	20	T	A	L	1-2	
U8	20	F	A	L	1-2	
V8	21	T	D	L	1-2	
W8	21	F	D	L	1-2	

Batch 1 (cont)

X8	22	T	B	L	1-2	
Y8	22	F	B	L	1-2	

Test Records BATCH 2
Delivered to AMTL 5/13/92

EXP. No.	PANEL	TEST	CORE	DEFECT	# SPEC.	
E6	9	T	A	I	1-6	
F6	9	F	A	I	1-6	
G6	12	T	D	I	1-6	
H6	12	F	D	I	1-6	
J6	16	T	B	I	1-6	
K6	16	F	B	I	1-6	
C5	6	T	S	CR	1-6	
C6	6	T	S	I	1-6	
D5	6	F	S	CR	1-6	
D6	6	F	S	I	1-6	
A1	1	F	S	V	1-27	
A5	2	F	S	CR	1-27	
B1	3	F	A	V	1-27	
B5	4	F	A	CR	1-27	
H1	14	F	D	V	1-6	
H2	14	F	D	UR	1-6	
H3	14	F	D	DF	1-6	
H4	14	F	D	DL	1-6	

Test Records BATCH #3
Delivered to AMTL 6/2/92

EXP. No.	PANEL	TEST	CORE	DEFECT	# SPEC.	
C1	5	T	S	V	1-6	
C2	5	T	S	UR	1-6	
C3	5	T	S	DF	1-6	
C4	5	T	S	DL	1-6	
D1	7	F	S	V	1-6	
D2	7	F	S	UR	1-6	
D3	7	F	S	DF	1-6	
D4	7	F	S	DL	1-6	
E1	8	T	A	V	1-6	
E2	8	T	A	UR	1-6	
E3	8	T	A	DF	1-6	
E4	8	T	A	DL	1-6	
G1	11	T	D	V	1-6	
G2	11	T	D	UR	1-6	
G3	11	T	D	DF	1-6	
G4	11	T	D	DL	1-6	
AA9	23	T	S	DRT	1-4	
AB9	23	F	S	DRT	1-4	
AC9	24	T	A	DRT	1-4	
AE9	24	T	D	DRT	1-4	

Batch 3 (cont)

AG9	24	T	B	DRT	1-4	
AD9	24	F	A	DRT	1-4	
AF9	24	F	D	DRT	1-4	
AH9	24	F	B	DRT	1-4	
J5	25	T	B	CR	1-6	
K5	25	F	B	CR	1-6	
E5	26	T	A	CR	1-6	
G5	26	T	D	CR	1-6	
F5	26	F	A	CR	1-6	
H5	26	F	D	CR	1-6	

APPENDIX C TEST DATA AND ANALYSIS

Appendices C1 and C2 contain individual experiment data sheets for each experiment conducted. These data sheets are the results of queries of the experiment summary database. This database was compiled by the testing laboratory from the raw test data and was supplied to the contractor in DBase IV™ format on 3.5" DOS floppy disks. The supplied files were converted and analyzed with the Paradox™ 3.5 database program. The strengths reported as final results are computed by dividing failure load by the specimen width. The width reported in these data sheets, and which was used in the computations of strength, is the average of the three width measurements made of each specimen, which are individually tabulated in the database.

C1 Data Sheets - Width Sensitivity Experiments

Experiment A1   Panel 1   Solid   Flexural   Voids

8/19   Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
1/A1-1-0	990	3.70	0.00		2.26	437
1/A1-10-0	1343	4.70	0.00		3.11	432
1/A1-19-0	1726	4.20	0.00		3.81	453
1/A1-2-.5	965	3.90	.50	v	2.27	426
1/A1-3-.5	928	4.50	.50	v	2.30	404
1/A1-11-.5	1281	4.10	.50	v	3.07	418
1/A1-12-.5	1223	4.50	.50	v	3.09	396
1/A1-21-.5	1691	3.60	.50	v	3.81	443
1/A1-20-.5	1603	3.60	.50	v	3.82	420
1/A1-4-1	908	4.00	1.00	v	2.27	401
1/A1-5-1	858	4.40	1.00	v	2.27	378
1/A1-13-1	1223	4.50	1.00	v	3.07	398
1/A1-14-1	1423	4.30	1.00	v	3.08	463
1/A1-22-1	1671	4.10	1.00	v	3.78	442
1/A1-23-1	1701	4.50	1.00	v	3.82	446
1/A1-7-1.5	1051	3.90	1.50	v	2.27	464
1/A1-6-1.5	985	4.10	1.50	v	2.27	434
1/A1-16-1.5	1286	3.60	1.50	v	3.06	420
1/A1-15-1.5	1191	3.90	1.50	v	3.08	387
1/A1-25-1.5	1556	4.30	1.50	v	3.79	411
1/A1-24-1.5	1533	4.40	1.50	v	3.81	402
1/A1-8-2	878	3.60	2.00	v	2.27	387
1/A1-9-2	925	4.00	2.00	v	2.27	407
1/A1-18-2	1373	4.50	2.00	v	3.07	447
1/A1-17-2	1396	3.80	2.00	v	3.12	448
1/A1-26-2	1608	3.80	2.00	v	3.79	424
1/A1-27-2	1461	4.20	2.00	v	3.80	384

Experiment A5   Panel 2   Solid   Flexural   Cracks

8/19   Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
2/A5-1-0	960	4.10	0.00		2.30	417
2/A5-10-0	1423	4.40	0.00		3.11	458
2/A5-19-0	1666	4.30	0.00		3.81	437
2/A5-3-.5	980	3.00	.50	cr	2.27	432
2/A5-2-.5	1003	3.90	.50	cr	2.27	442
2/A5-12-.5	1398	3.60	.50	cr	3.08	454
2/A5-11-.5	1401	3.60	.50	cr	3.08	454
2/A5-21-.5	1716	3.60	.50	cr	3.81	450
2/A5-20-.5	1808	3.80	.50	cr	3.82	474
2/A5-4-1	895	3.00	1.00	cr	2.27	395
2/A5-5-1	935	2.90	1.00	cr	2.27	413
2/A5-14-1	1318	3.20	1.00	cr	3.09	427
2/A5-13-1	1298	4.10	1.00	CR	3.12	417
2/A5-23-1	1733	3.20	1.00	cr	3.80	456
2/A5-22-1	1728	3.70	1.00	cr	3.91	442
2/A5-7-1.5	888	2.80	1.50	cr	2.26	393
2/A5-6-1.5	893	2.90	1.50	cr	2.27	394
2/A5-15-1.5	1341	3.40	1.50	cr	3.08	435
2/A5-16-1.5	1258	2.70	1.50	cr	3.09	408
2/A5-24-1.5	1601	3.70	1.50	cr	3.82	419
2/A5-25-1.5	1608	3.40	1.50	cr	3.83	420
2/A5-9-2	930	2.80	2.00	cr	2.26	411
2/A5-8-2	893	2.50	2.00	cr	2.27	394
2/A5-18-2	1186	2.80	2.00	cr	3.08	385
2/A5-17-2	1248	2.90	2.00	cr	3.08	405
2/A5-27-2	1451	2.90	2.00	cr	3.81	381
2/A5-26-2	1523	2.90	2.00	cr	3.82	399

Experiment B1 Panel 3 Airex Flexural Voids

8/19 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
3/B1-1-0	335	1.80	0.00		2.27	147
3/B1-10-0	426	1.60	0.00	0	3.07	139
3/B1-19-0	587	1.90	0.00	0	3.86	152
3/B1-2-.5	387	2.40	.50	v	2.26	171
3/B1-3-.5	333	1.90	.50	v	2.26	147
3/B1-11-.5	467	1.80	.50	v	3.06	152
3/B1-12-.5	440	1.80	.50	v	3.07	143
3/B1-20-.5	544	1.70	.50	v	3.92	139
3/B1-21-.5	577	1.90	.50	v	3.92	147
3/B1-5-1	348	2.10	1.00	v	2.23	156
3/B1-4-1	339	1.90	1.00	v	2.23	152
3/B1-14-1	485	2.00	1.00	v	3.05	159
3/B1-13-1	430	1.50	1.00	v	3.06	140
3/B1-22-1	579	1.80	1.00	v	3.91	148
3/B1-23-1	615	2.00	1.00	v	3.92	157
3/B1-6-1.5	313	1.70	1.50	v	2.24	140
3/B1-7-1.5	343	1.70	1.50	v	2.26	152
3/B1-16-1.5	447	1.90	1.50	v	3.06	146
3/B1-15-1.5	492	2.00	1.50	v	3.07	160
3/B1-24-1.5	508	1.60	1.50	v	3.92	130
3/B1-25-1.5	563	1.70	1.50	v	3.92	144
3/B1-9-2	320	2.00	2.00	v	2.24	143
3/B1-8-2	306	1.40	2.00	v	2.26	135
3/B1-17-2	482	2.10	2.00	v	3.06	157
3/B1-18-2	443	1.70	2.00	v	3.06	145
3/B1-26-2	540	1.80	2.00	v	3.91	138
3/B1-27-2	545	1.70	2.00	v	3.92	139

Experiment B5   Panel 4   Airex   Flexural Cracks

8/19   Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
4/B5-1-0	282	1.60	0.00		2.25	125
4/B5-10-0	406	1.90	0.00	0	3.07	132
4/B5-19-0	564	2.10	0.00		3.92	144
4/B5-3-.5	330	2.20	.50	cr	2.22	149
4/B5-2-.5	329	2.20	.50	cr	2.24	147
4/B5-12-.5	409	2.00	.50	cr	3.06	[illegible]
4/B5-11-.5	444	2.00	.50	cr	3.06	[illegible]
4/B5-20-.5	488	1.70	.50	cr	3.92	125
4/B5-21-.5	504	1.80	.50	cr	3.92	129
4/B5-5-1	309	1.80	1.00	cr	2.27	136
4/B5-4-1	320	1.90	1.00	cr	2.58	124
4/B5-13-1	465	2.10	1.00	cr	3.06	152
4/B5-14-1	384	1.80	1.00	cr	3.06	125
4/B5-22-1	550	2.00	1.00	cr	3.91	141
4/B5-23-1	578	2.10	1.00	cr	3.92	148
4/B5-6-1.5	308	1.90	1.50	cr	2.26	136
4/B5-7-1.5	318	1.80	1.50	cr	2.27	140
4/B5-16-1.5	424	1.90	1.50	cr	3.06	138
4/B5-15-1.5	438	2.00	1.50	cr	3.07	143
4/B5-24-1.5	518	1.70	1.50	cr	3.91	132
4/B5-25-1.5	472	1.50	1.50	cr	3.92	120
4/B5-9-2	271	1.40	2.00	cr	2.24	121
4/B5-8-2	294	1.60	2.00	cr	2.28	129
4/B5-17-2	400	1.20	2.00	cr	3.06	131
4/B5-18-2	448	2.00	2.00	cr	3.06	146
4/B5-27-2	538	1.70	2.00	cr	3.91	138
4/B5-26-2	565	2.10	2.00	cr	3.92	144

C2 Data Sheets - Defect Size Experiments

Experiment C1 Panel 5 Solid Tensile Voids

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
5/C1-1-0	72713	0	0.00		3.76	19320
5/C1-6-0	76416	0	0.00		3.77	20287
5/C1-2-1	68158	18136	1.00	V	3.77	18085
5/C1-3-1	73413	21111	1.00	V	3.75	19592
5/C1-4-2	68859	21243	2.00	V	3.77	18250
5/C1-5-2	71562	0	2.00	V	3.66	19565

Experiment C2 Panel 5 Solid Tensile Uncured Resin

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
5/C2-6-0	69960	19326	0.00		3.77	18564
5/C2-1-0	74264	21772	0.00		3.76	19756
5/C2-2-1	68759	18070	1.00	UR	3.79	18120
5/C2-3-1	72863	20714	1.00	UR	3.77	19344
5/C2-4-2	72563	20251	2.00	UR	3.66	19835
5/C2-5-2	74815	21111	2.00	UR	3.77	19843

Experiment C3 Panel 5 Solid Tensile Dry Fibers

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
5/C3-6-0	71111	19425	0.00		3.76	18919
5/C3-1-0	75265	21309	0.00		3.77	19975
5/C3-2-1	72863	0	1.00	DF	3.79	19213
5/C3-3-1	74665	0	1.00	DF	3.76	19856
5/C3-5-2	72563	35060	2.00	DF	3.77	19266
5/C3-4-2	74464	0	2.00	DF	3.77	19773

Experiment C4 Panel 5 Solid Tensile Delamination

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
5/C4-6-0	73914	21289	0.00		3.77	19621
5/C4-1-0	76817	0	0.00		3.77	20388
5/C4-2-1	73664	21342	1.00	DL	3.76	19567
5/C4-3-1	75465	21743	1.00	DL	3.76	20051
5/C4-5-2	68108	20633	2.00	DL	3.77	18087
5/C4-4-2	73614	24416	2.00	DL	3.80	19370

Experiment C5 Panel 6 Solid Tensile Cracks

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
6/C5-1-0	73864	19650	0.00		3.78	19525
6/C5-6-0	75415	17909	0.00		3.81	19804
6/C5-3-1	65556	0	1.00	CR	3.83	17139
6/C5-2-1	69359	21037	1.00	CR	3.81	18219
6/C5-4-2	62803	0	2.00	CR	3.81	16466
6/C5-5-2	65455	0	2.00	CR	3.81	17163

Experiment C6 Panel 6 Solid Tensile Impact

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
6/C6-6-0	67658	17574	0.00		3.82	17691
6/C6-1-0	71812	0	0.00		3.83	18771
6/C6-2-0	73463	20381	40.00	I	3.82	19214
6/C6-3-0	73514	0	40.00	I	3.82	19229
6/C6-4-0	56747	14404	80.00	I	3.82	14845
6/C6-4-0	73463	18666	80.00	I	3.82	19218
6/C6-5-0	74314	22247	80.00	I	3.81	19483

Experiment E1 Panel 8 Airex Tensile Voids

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
8/E1-1-0	9841	15106	0.00		3.75	2624
8/E1-6-0	10781	18984	0.00		3.76	2866
8/E1-2-1	9141	17960	1.00	V	3.75	2435
8/E1-3-1	10301	19605	1.00	V	3.76	2740
8/E1-5-2	9961	22087	2.00	V	3.75	2658
8/E1-4-2	10001	21281	2.00	V	3.72	2690

Experiment E2 Panel 8 Airex Tensile Uncured Resin

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
8/E2-1-0	9781	18798	0.00		3.74	2612
8/E2-6-0	10461	17433	0.00		3.76	2785
8/E2-2-1	9701	14950	1.00	UR	3.74	2591
8/E2-3-1	10401	20536	1.00	UR	3.73	2788
8/E2-4-2	10041	17619	2.00	UR	3.72	2702
8/E2-5-2	10481	18364	2.00	UR	3.74	2802

Experiment E3 Panel 8 Airex Tensile Dry Fibers

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
8/E3-1-0	10401	17619	0.00		3.75	2776
8/E3-6-0	10621	17774	0.00		3.75	2832
8/E3-3-1	9521	21715	1.00	DF	3.75	2540
8/E3-2-1	10321	23391	1.00	DF	3.75	2754
8/E3-4-2	8861	27052	2.00	DF	3.75	2365
8/E3-5-2	9461	17929	2.00	DF	3.74	2528

Experiment E4 Panel 8 Airex Tensile Delamination

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
8/E4-1-0	9501	17464	0.00		3.75	2532
8/E4-6-0	10181	0	0.00		3.75	2712
8/E4-3-1	9541	13833	1.00	DL	3.74	2548
8/E4-2-1	10601	17805	1.00	DL	3.75	2828
8/E4-4-2	9441	17402	2.00	DL	3.75	2518
8/E4-5-2	10221	17712	2.00	DL	3.75	2724

Experiment E5 Panel 26 Airex Tensile Cracks

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
26/E5-6-0	10341	18548	0.00		3.75	2756
26/E5-1-0	11061	16606	0.00		3.75	2946
26/E5-3-1	8621	12265	1.00	CR	3.75	2297
26/E5-2-1	10101	15543	1.00	CR	3.75	2691
26/E5-4-2	6921	11810	2.00	CR	3.74	1849
26/E5-5-2	8441	12994	2.00	CR	3.75	2249

Experiment E6 Panel 9 Airex Tensile Impact

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
9/E6-6-0	10541	19764	0.00		3.86	2733
9/E6-2-0	10321	16290	15.00	I	3.85	2678
9/E6-1-0	10561	17548	15.00	I	3.85	2745
9/E6-4-0	10041	22159	30.00	I	3.85	2610
9/E6-5-0	10161	22309	30.00	I	3.86	2633
9/E6-3-0	5761	57765	40.00	I	3.85	1495

Experiment G1 Panel 11 Divinycell Tensile Voids

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
11/G1-1-0	9721	0	0.00		3.76	2584
11/G1-6-0	10661	17881	0.00		3.76	2833
11/G1-2-1	9061	0	1.00	V	3.69	2454
11/G1-3-1	9341	13753	1.00	V	3.76	2486
11/G1-4-2	8861	12417	2.00	V	3.76	2355
11/G1-5-2	9541	18761	2.00	V	3.76	2536

Experiment G2 Panel 11 Divinycell Tensile Uncured Resin

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
11/G2-1-0	9961	13783	0.00		3.75	2658
11/G2-6-0	10781	16545	0.00		3.76	2866
11/G2-3-1	9681	0	1.00	UR	3.76	2578
11/G2-2-1	10181	16515	1.00	UR	3.76	2710
11/G2-5-2	9701	21189	2.00	UR	3.74	2594
11/G2-4-2	11121	13363	2.00	UR	3.76	2961

Experiment G3 Panel 11 Divinycell Tensile Dry Fibers

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
11/G3-6-0	8721	12751	0.00		3.75	2329
11/G3-1-0	10161	0	0.00		3.76	2702
11/G3-3-1	10221	26834	1.00	DF	3.75	2727
11/G3-2-1	10961	22707	1.00	DF	3.75	2925
11/G3-4-2	8241	18063	2.00	DF	3.75	2200
11/G3-5-2	9621	19793	2.00	DF	3.74	2572

Experiment G4   Panel 11   Divinycell   Tensile   Delamination

8/19   Strength [illegible]ort

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
11/G4-1-0	10441	18275	0.00		3.74	2790
11/G4-6-0	11000	17243	0.00		3.76	2927
11/G4-3-1	9361	14572	1.00	DL	3.74	2503
11/G4-2-1	10161	16484	1.00	DL	3.75	2712
11/G4-4-2	9921	15938	2.00	DL	3.71	2672
11/G4-5-2	10561	15817	2.00	DL	3.73	2830

Experiment G5 Panel 26 Divinycell Tensile Cracks

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
26/G5-6-0	8941	13892	0.00		3.74	2388
26/G5-1-0	11041	19161	0.00		3.76	2939
26/G5-2-1	8581	13185	1.00	CR	3.75	2288
26/G5-3-1	9161	14663	1.00	CR	3.74	2450
26/G5-4-2	7801	12221	2.00	CR	3.69	2115
26/G5-5-2	8101	11868	2.00	CR	3.74	2166

Experiment G6 Panel 12 Divinycell Tensile Impact

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
12/G6-6-0	11481	15841	0.00		3.91	2937
12/G6-1-0	11841	17967	0.00		3.92	3024
12/G6-2-0	10481	23507	15.00	I	3.91	2679
12/G6-3-0	11581	19284	15.00	I	3.91	2959
12/G6-5-0	10201	20931	30.00	I	3.91	2606
12/G6-4-0	10821	16799	30.00	I	3.91	2769

Experiment J1 Panel 15 Balsa Tensile Voids

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
15/J1-6-0	10381	14599	0.00		3.76	2762
15/J1-1-0	10481	14823	0.00		3.75	2794
15/J1-3-1	9961	14727	1.00	V	3.77	2646
15/J1-2-1	10041	16783	1.00	V	3.72	2696
15/J1-5-2	10301	0	2.00	V	3.75	2744
15/J1-4-2	10421	16269	2.00	V	3.76	2770

Experiment J2 Panel 15 Balsa Tensile Uncured Resin

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
15/J2-6-0	9641	13442	0.00		3.74	2576
15/J2-1-0	10041	13378	0.00		3.75	2674
15/J2-2-1	10321	17265	1.00	UR	3.73	2767
15/J2-3-1	10801	15241	1.00	VR	3.75	2881
15/J2-4-2	10521	16912	2.00	UR	3.76	2801
15/J2-5-2	11141	16398	2.00	UR	3.75	2969

Experiment J3 Panel 15 Balsa Tensile Dry Fibers

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
15/J3-1-0	9821	13474	0.00		3.74	2623
15/J3-6-0	10181	15659	0.00		3.76	2711
15/J3-2-1	8341	0	1.00	DF	3.75	2222
15/J3-3-1	8801	0	1.00	DF	3.76	2340
15/J3-5-2	7781	0	2.00	DF	3.75	2077
15/J3-4-2	8481	0	2.00	DF	3.76	2255

Experiment J4 Panel 15 Balsa Tensile Delamination

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
15/J4-1-0	9421	13956	0.00		3.75	2512
15/J4-6-0	10361	15498	0.00		3.76	2759
15/J4-2-1	9461	0	1.00	DL	3.60	2629
15/J4-3-1	10401	16590	1.00	DL	3.75	2773
15/J4-4-2	9721	14695	2.00	DL	3.75	2590
15/J4-5-2	10281	16333	2.00	DL	3.76	2736

Experiment J5 Panel 25 Balsa Tensile Cracks

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
25/J5-6-0	10101	16150	0.00		3.75	2692
25/J5-1-0	10641	0	0.00		3.75	2837
25/J5-2-1	7461	0	1.00	CR	3.75	1988
25/J5-3-1	8401	10991	1.00	CR	3.75	2240
25/J5-4-2	5841	8623	2.00	CR	3.76	1556
25/J5-5-2	6241	8684	2.00	CR	3.76	1662

Experiment J6 Panel 16 Balsa Tensile Impact

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
16/J6-1-0	11301	14523	0.00		3.92	2883
16/J6-6-0	11461	12726	0.00		3.92	2927
16/J6-4-0	10221	19314	20.00	I	3.91	2615
16/J6-5-0	11101	16889	20.00	I	3.91	2838
16/J6-3-0	0	0	40.00	I	3.91	0
16/J6-2-0	9501	22010	40.00	I	3.91	2431

Experiment L7 Panel 18 Airex Tensile Core Filling

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
18/L7-1-1	10800	16840	1.00	CF	3.89	2774
18/L7-2-1	11200	16840	1.00	CF	3.90	2874
18/L7-3-2	10460	16110	2.00	CF	3.89	2688
18/L7-4-2	10900	16450	2.00	CF	3.90	2798

Experiment N7 Panel 18 Divinycell Tensile Core Filling

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
18/N7-2-1	10220	17480	1.00	CF	3.91	2616
18/N7-1-1	10700	17070	1.00	CF	3.93	2723
18/N7-4-2	10841	18480	2.00	CF	3.88	2791
18/N7-3-2	11500	19988	2.00	CF	3.89	2953

Experiment P7 Panel 18 Balsa Tensile Core Filling

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
18/P7-2-1	9880	15220	1.00	CF	3.84	2572
18/P7-1-1	10500	16010	1.00	CF	3.84	2735
18/P7-3-2	9400	0	2.00	CF	3.89	2414
18/P7-4-2	9500	0	2.00	CF	3.84	2472

Experiment R8 Panel 19 Solid Tensile Lapped Reinforcement

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
19/R8-1	71500	0	4.00	L	3.88	18439
19/R8-2	74915	0	4.00	L	3.89	19244

Experiment T8 Panel 20 Airex Tensile Lapped Reinforcement

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
20/T8-1	9821	10630	4.00	L	3.92	2507
20/T8-2	10540	10115	[illegible].00	L	3.91	2694

Experiment V8   Panel 21   Divinycell   Tensile   Lapped Reinforcement

8/19   Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
21/V8-2	10620	11200	4.00	L	3.93	2705
21/V8-1	10800	12050	4.00	L	3.93	2750

Experiment X8 Panel 22 Balsa Tensile Lapped Reinforcement

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
22/X8-1	10600	11355	4.00	L	3.92	2701
22/X8-2	11320	12020	4.00	L	3.92	2891

Experiment AA9 Panel 23 Solid Tensile Dirt

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
23/AA9-2-0	68909	18036	0.00		3.77	18294
23/AA9-1-0	71862	18162	0.00		3.78	19028
23/AA9-3-4	73864	21541	4.00	D	3.77	19596
23/AA9-4-4	77568	22953	4.00	D	3.77	20564

Experiment AC9 Panel 24 Airex Tensile Dirt

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
24/AC9-2-0	10341	17941	0.00		3.71	2788
24/AC9-1-0	10681	16879	0.00		3.76	2842
24/AC9-3-4	6821	0	4.00	D	3.76	1814
24/AC9-4-4	8681	20764	4.00	D	3.72	2337

Experiment AE9 Panel 24 Divinycell Tensile Dirt

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
24/AE9-2-0	11041	17774	0.00		3.71	2975
24/AE9-1-0	11361	22056	0.00		3.76	3025
24/AE9-4-4	10081	24322	4.00	D	3.76	2681
24/AE9-3-4	10741	20443	4.00	D	3.74	2869

Experiment AG9 Panel 24 Balsa Tensile Dirt

8/19 Strength Report

Specnum	Pmax	Strain	Dsize	Dtype	Width	Strength
24/AG9-1-0	9781	0	0.00		3.76	2601
24/AG9-2-0	10241	17304	0.00		3.60	2843
24/AG9-4-4	9601	20643	4.00	D	3.75	2560
24/AG9-3-4	9661	20187	4.00	D	3.76	2572

Experiment D1 Panel 7 Solid Flexural Voids

7/31 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
7/D1-1-0	1573	4.20	0.00		3.76	418
7/D1-6-0	1693	4.10	0.00		3.76	450
7/D1-2-1	1588	4.00	1.00	v	3.76	422
7/D1-3-1	1531	4.10	1.00	v	3.77	406
7/D1-4-2	1546	4.20	2.00	v	3.79	407
7/D1-5-2	1561	4.40	2.00	v	3.76	415

Experiment D2 Panel 7 Solid Flexural Uncured Resin

7/31 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
7/D2-1-0	1536	4.30	0.00		3.77	408
7/D2-6-0	1528	4.30	0.00		3.77	405
7/D2-2-1	1628	4.90	1.00	ur	3.77	432
7/D2-3-1	1558	4.20	1.00	ur	3.76	414
7/D2-4-2	1643	4.70	2.00	ur	3.80	432
7/D2-5-2	1496	4.30	2.00	ur	3.77	397

Experiment D3 Panel 7 Solid Flexural Dry Fibers

7/31 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
7/D3-1-0	1581	4.30	0.00		3.77	420
7/D3-6-0	1636	4.20	0.00		3.76	435
7/D3-2-1	1723	4.60	1.00	df	3.79	454
7/D3-3-1	1578	3.80	1.00	df	3.75	421
7/D3-4-2	1566	4.10	2.00	df	3.76	416
7/D3-5-2	1608	4.30	2.00	df	3.76	427

Experiment D4 Panel 7 Solid Flexural Delamination

7/31 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
7/D4-1-0	1601	4.10	0.00		3.77	424
7/D4-6-0	1618	4.30	0.00		3.77	429
7/D4-2-1	1686	2.40	.50	dl	3.79	445
7/D4-3-1	1708	2.30	1.00	dl	3.76	454
7/D4-4-2	1646	4.50	2.00	dl	3.77	436
7/D4-5-2	1668	3.90	2.00	dl	3.77	443

Experiment D5 Panel 6 Solid Flexural Cracks

8/19 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
6/D5-6-0	1623	4.50	0.00		3.89	417
6/D5-1-0	1718	4.40	0.00		3.83	449
6/D5-2-1	1488	4.40	1.00	cr	3.82	389
6/D5-3-1	1583	4.40	1.00	cr	3.83	414
6/D5-4-2	1588	2.90	2.00	CR	3.83	415
6/D5-5-2	1588	3.00	2.00	cr	3.81	417

Experiment D6 Panel 6 Solid Flexural Impact

8/19 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
6/D6-1-0	1671	4.10	0.00		3.82	437
6/D6-6-0	1733	3.80	0.00		3.82	453
6/D6-3-0	1748	3.60	40.00	i	3.82	458
6/D6-2-0	1813	3.90	40.00	i	3.87	468
6/D6-5-0	1588	4.80	80.00	i	3.82	416
6/D6-4-0	1626	3.70	80.00	i	3.82	426

Experiment F1 Panel 10 Airex Flexural Voids

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
10/F1-1-0	535	1.60	0.00	0	3.89	137
10/F1-6-0	613	2.30	0.00	0	3.89	158
10/F1-2-1	549	1.80	1.00	v	3.88	141
10/F1-3-1	569	1.80	1.00	v	3.89	146
10/F1-4-2	618	2.60	2.00	v	3.89	159
10/F1-5-2	597	2.50	2.00	v	3.89	154

Experiment F2 Panel 10 Airex Flexural Uncured Resin

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
10/F2-1-0	538	2.00	0.00		3.87	139
10/F2-6-0	550	2.20	0.00	0	3.87	142
10/F2-2-1	605	2.60	1.00	ur	3.88	156
10/F2-3-1	618	2.10	1.00	ur	3.86	160
10/F2-4-2	618	2.30	2.00	ur	3.87	159
10/F2-5-2	580	2.10	2.00	ur	3.88	150

Experiment F3 Panel 10 Airex Flexural Dry Fibers

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
10/F3-1-0	575	2.00	0.00	00	3.89	148
10/F3-6-0	638	3.00	0.00	00	3.88	164
10/F3-2-1	646	2.50	1.00	df	3.90	166
10/F3-3-1	508	1.80	1.00	df	3.88	131
10/F3-4-2	536	1.90	2.00	df	3.87	139
10/F3-5-2	536	2.30	2.00	df	3.89	138

Experiment F4 Panel 10 Airex Flexural Delamination

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
10/F4-1-0	598	2.30	0.00	0	3.87	155
10/F4-6-0	600	2.30	0.00	0	3.88	155
10/F4-2-1	600	2.50	1.00	dl	3.85	156
10/F4-3-1	553	2.10	1.00	dl	3.86	143
10/F4-4-2	555	2.10	2.00	dl	3.88	143
10/F4-5-2	570	2.30	2.00	dl	3.89	147

Experiment F5   Panel 26   Airex Flexural   Cracks

8/18   Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
26/F5-6-0	440	1.70	0.00		3.76	117
26/F5-2-1	489	1.90	1.00	cr	3.76	130
26/F5-3-1	512	1.90	1.00	cr	3.76	136
26/F5-4-2	512	1.90	2.00	cr	3.76	136
26/F5-5-2	526	2.00	2.00	cr	3.76	140

Experiment F6 Panel 9 Airex Flexural Impact

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
9/F6-1-0	640	2.30	0.0	0	3.86	166
9/F6-6-0	658	2.50	0.0		3.85	171
9/F6-2-0	574	2.10	15.0	i	3.86	149
9/F6-3-0	553	1.90	15.0	i	3.86	143
9/F6-4-0	580	1.90	30.0	i	3.86	150
9/F6-5-0	590	2.20	30.0	i	3.86	153

Experiment H1 Panel 14 Divinycell Flexural Voids

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
14/H1-1-0	588	1.50	0.00		3.92	150
14/H1-6-0	571	1.50	0.00		3.86	148
14/H1-2-1	640	1.80	1.00	v	3.86	166
14/H1-3-1	698	1.80	1.00	v	3.91	179
14/H1-4-2	582	1.70	2.00	v	3.85	151
14/H1-5-2	569	1.60	2.00	v	3.86	148

Experiment H2 Panel 14 Divinycell Flexural Uncured Resin

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
14/H2-1-0	480	1.40	0.00		3.86	124
14/H2-6-0	574	1.70	0.00		3.86	149
14/H2-2-1	566	1.60	1.00	ur	3.86	147
14/H2-3-1	598	1.70	1.00	ur	3.86	155
14/H2-4-2	572	1.50	2.00	ur	3.86	148
14/H2-5-2	527	1.50	2.00	ur	3.86	137

Experiment H3 Panel 14 Divinycell Flexural Dry Fibers

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
14/H3-1-0	696	1.90	0.00		3.86	180
14/H3-2-1	672	2.30	1.00	df	3.84	175
14/H3-3-1	568	1.50	1.00	df	3.86	147
14/H3-4-2	586	1.80	2.00	df	3.85	152
14/H3-5-2	682	2.10	2.00	df	3.85	177

Experiment H4   Panel 14   Divinycell   Flexural   Delamination

8/18   Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
14/H4-1-0	620	1.70	0.00		3.85	161
14/H4-6-0	557	1.70	0.00		3.86	144
14/H4-2-1	590	1.70	1.00	dl	3.85	153
14/H4-3-1	508	1.40	1.00	dl	4.86	105
14/H4-4-2	667	2.00	2.00	dl	3.84	174
14/H4-5-2	518	1.30	2.00	dl	3.86	134

Experiment H5 Panel 26 Divinycell Flexural Cracks

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
26/H5-1-0	485	1.90	0.00		3.76	129
26/H5-6-0	486	1.70	0.00		3.75	129
26/H5-2-1	628	1.90	1.00	cr	3.74	168
26/H5-3-1	597	1.80	1.00	cr	3.74	160
26/H5-4-2	536	1.70	2.00	cr	3.76	142
26/H5-5-2	478	1.70	2.00	cr	3.76	127

Experiment H6 Panel 12 Divinycell Flexural Impact

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
12/H6-6-0	589	1.60	0.0		3.92	150
12/H6-1-0	590	1.60	0.0		3.92	151
12/H6-2-0	641	2.20	15.0	i	3.92	164
12/H6-3-0	647	2.00	15.0	i	3.91	165
12/H6-5-0	515	1.50	30.0	i	3.92	131
12/H6-4-0	543	1.60	30.0	i	3.92	138

Experiment K1 Panel 17 Balsa Flexural Voids

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
17/K1-6-0	805	2.70	0.00	0	3.88	208
17/K1-1-0	811	3.10	0.00	0	3.88	209
17/K1-2-1	780	2.90	1.00	v	3.88	201
17/K1-3-1	808	3.10	1.00	v	3.88	208
17/K1-4-2	657	2.50	2.00	v	3.88	169
17/K1-5-2	732	2.70	2.00	v	3.88	189

Experiment K2 Panel 17 Balsa Flexural Uncured Resin

8/18 Strength Report

Specnum	Fmax	Defl	Dsize	Dtype	Width	Strength
17/K2-1-0	8[illegible]0	3.10	0.00	0	3.95	210
17/K2-6-0	808	3.00	0.00	0	3.95	205
17/K2-1-UR	758	2.70	1.00	ur	3.88	195
17/K2-3-1	707	2.60	1.00	ur	3.87	183
17/K2-4-2	702	2.80	2.00	ur	3.85	183
17/K2-5-2	705	2.40	2.00	ur	3.88	182

Experiment K3 Panel 17 Balsa Flexural Dry Fibers

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
17/K3-1-0	705	2.50	0.00	0	3.87	182
17/K3-6-0	740	2.70	0.00	0	3.88	191
17/K3-2-1	700	2.30	1.00	df	3.96	177
17/K3-3-1	705	2.50	1.00	df	3.94	179
17/K3-4-2	677	2.40	2.00	df	3.95	171
17/K3-5-2	640	2.20	2.00	df	3.87	165

Experiment K4 Panel 17 Balsa Flexural Delamination

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
17/K4-6-0	726	2.40	0.00	0	3.88	187
17/K4-1-0	756	2.70	0.00	0	3.88	195
17/K4-2-1	735	2.50	1.00	dl	3.88	189
17/K4-3-1	753	2.60	1.00	dl	3.88	194
17/K4-5-2	707	2.50	2.00	dl	3.87	183
17/K4-4-2	728	3.00	2.00	dl	3.88	188

Experiment K5 Panel 25 Balsa Flexural Cracks

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
25/K5-1-0	696	2.40	0.00		3.74	186
25/K5-6-0	768	2.80	0.00		3.78	203
25/K5-2-1	547	1.70	1.00	cr	3.73	147
25/K5-3-1	585	1.70	1.00	cr	3.75	156
25/K5-5-2	457	1.30	2.00	cr	3.75	122
25/K5-4-2	546	1.60	2.00	cr	3.78	144

Experiment K6   Panel 16   Balsa   Flexural   Impact

8/18   Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
16/K6-1-0	753	2.60	0.0	00	3.92	192
16/K6-6-0	830	3.00	0.0		3.92	212
16/K6-4-0	683	2.10	20.0	i	3.91	175
16/K6-5-0	789	3.00	20.0	i	3.92	201
16/K6-3-0	619	1.70	40.0	i	3.91	158
16/K6-2-0	708	2.20	40.0	i	3.92	181

Experiment M7 Panel 18 Airex Flexural Core Filling

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
18/M7-1-1	474	1.60	1.00	cf	3.90	121
18/M7-2-1	480	1.60	1.00	cf	3.91	123
18/M7-3-2	463	1.50	2.00	cf	3.90	119
18/M7-4-2	554	1.90	2.00	cf	3.90	142

Experiment 07 Panel 18 Divinycell Flexural Core Filling

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
18/07-1-1	484	1.40	1.00	cf	3.91	124
18/07-2-1	548	1.60	1.00	cf	3.91	140
18/07-3-2	626	2.00	1.00	cf	3.91	160
18/07-4-2	590	1.80	2.00	cf	3.91	151

Experiment Q7 Panel 18 Balsa Flexural Core Filling

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
18/Q7-2-1	793	3.00	1.00	cf	3.90	203
18/Q7-1-1	805	3.00	1.00	cf	3.89	207
18/Q7-3-2	680	2.20	2.00	cf	3.89	175
18/Q7-4-2	785	2.90	2.00	cf	3.89	202

Experiment S8 Panel 19 Solid Flexural Lapped Reinforcement

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
19/S8-1	1760	4.20	0.00	l	3.87	455
19/S8-2	1910	3.70	0.00	L	3.88	492

Experiment U8 Panel 20 Airex Flexural Lapped Reinforcement

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
20/U8-1	563	1.50	0.00	1	3.94	143
20/U8-2	546	1.40	0.00	1	3.94	139

Experiment Y8 Panel 22 Balsa Flexural Lapped Reinforcement

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
22/Y8-1	898	2.60	0.00	1	3.92	229
22/Y8-2	873	2.50	0.00	1	3.92	223

Experiment AB9 Panel 23 Solid Flexural Dirt

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
23/AB9-1-0	1351	4.50	0.00		3.76	359
23/AB9-2-0	1631	4.30	0.00		3.77	432
23/AB9-3-4	1441	4.20	4.00	d	3.77	382
23/AB9-4-4	1406	4.50	4.00	d	3.78	372

Experiment AD9 Panel 24 Airex Flexural Dirt

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
24/AD9-1-0	465	1.60	0.00		3.77	123
24/AD9-2-0	490	2.00	0.00		3.75	131
24/AD9-3-4	487	2.10	4.00	d	3.76	130
24/AD9-4-4	457	2.00	4.00	d	3.76	122

Experiment AF9 Panel 24 Divinycell Flexural Dirt

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
24/AF9-1-0	431	1.40	0.00		3.75	115
24/AF9-2-0	481	1.60	0.00		3.68	131
24/AF9-3-4	501	1.70	4.00	d	3.76	133
24/AF9-4-4	484	1.60	4.00	d	3.75	129

Experiment AH9 Panel 24 Balsa Flexural Dirt

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Dtype	Width	Strength
24/AH9-1-0	732	2.70	0.00		3.76	195
24/AH9-2-0	696	2.70	0.00		3.75	185
24/AH9-3-4	660	2.10	4.00	d	3.75	176
24/AH9-4-4	625	1.90	4.00	d	3.75	167

C3 Load-Deflection Plots - Defect Size Experiments

Figures C3-1 through C3-8 are a representative sample of load/deflection plots. These plots were created from the raw data recorded by the testing machines, which was transferred as ASCII data files. The data points used to generate the plots were taken every 0.5 sec. For tensile tests, the files contain three columns of data: time (seconds), load (lbf), and microstrain (μinches/inch). Files for flexural tests also have three columns: time (seconds), load (lbf), and specimen deflection at the center of the support span (inches).

For tensile specimens, load is plotted against microstrain units (microinches/inch). For flexural plots, load is plotted against deflection. For those load-deflection plots of flexural tests in which loads exceeded 1000 lbf, the y-axis (representing load) is broken at 1000 lbf for compactness of presentation. Adding 1000 lbf to ordinates beyond the break will yield the actual force values.

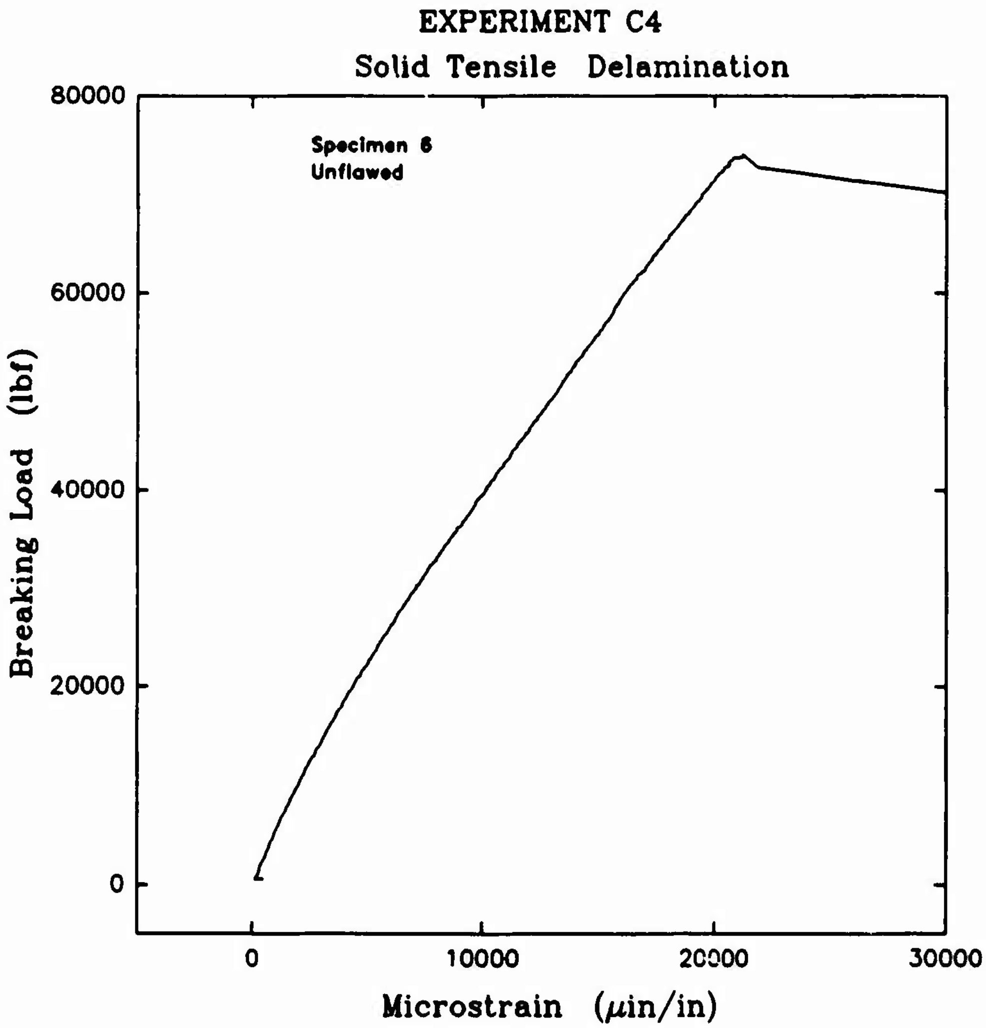

EXPERIMENT C4
Solid Tensile Delamination
Specimen 6
Unflawed
80000
60000
40000
20000
0
Breaking Load (lbf)
0
10000
20000
30000
Microstrain (μin/in)

Figure C3-1

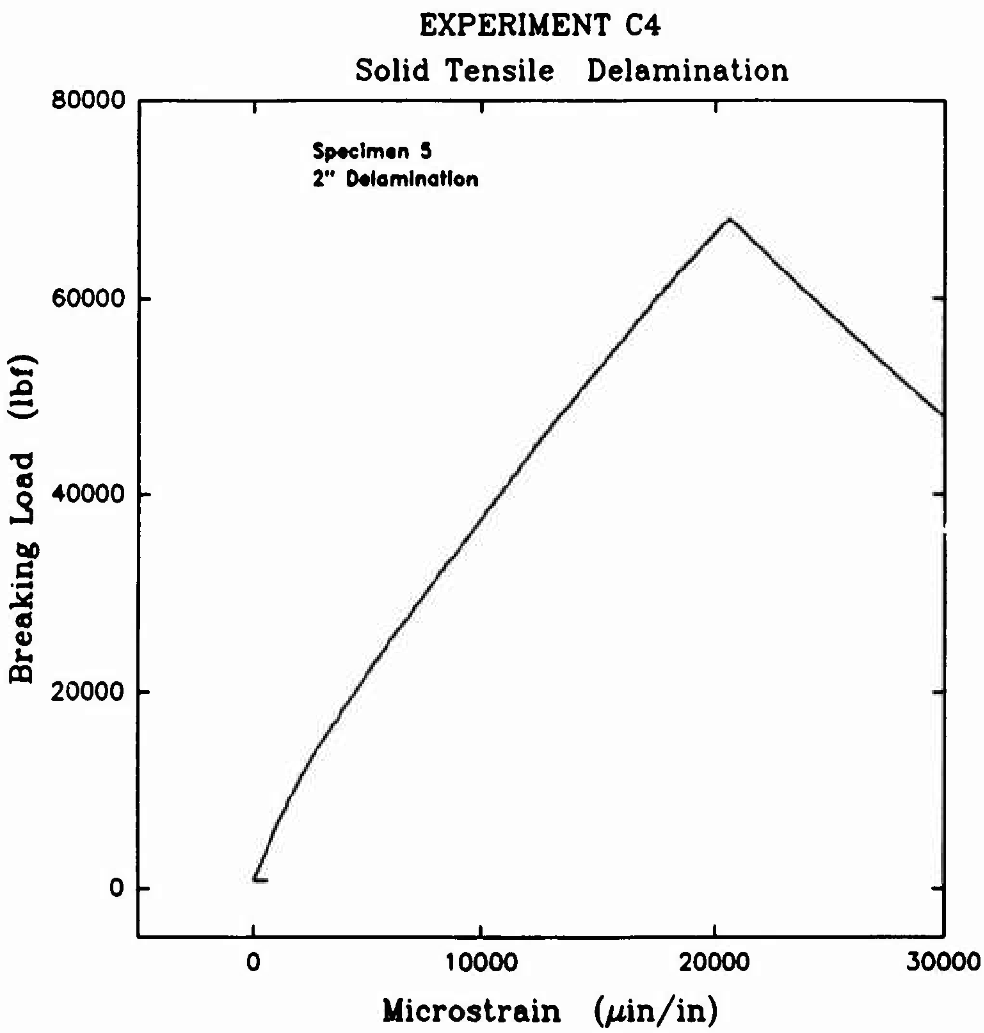

EXPERIMENT C4
Solid Tensile Delamination
Specimen 5
2" Delamination
Breaking Load (lbf)
80000
60000
40000
20000
0
0
10000
20000
30000
Microstrain (μin/in)

Figure C3-2

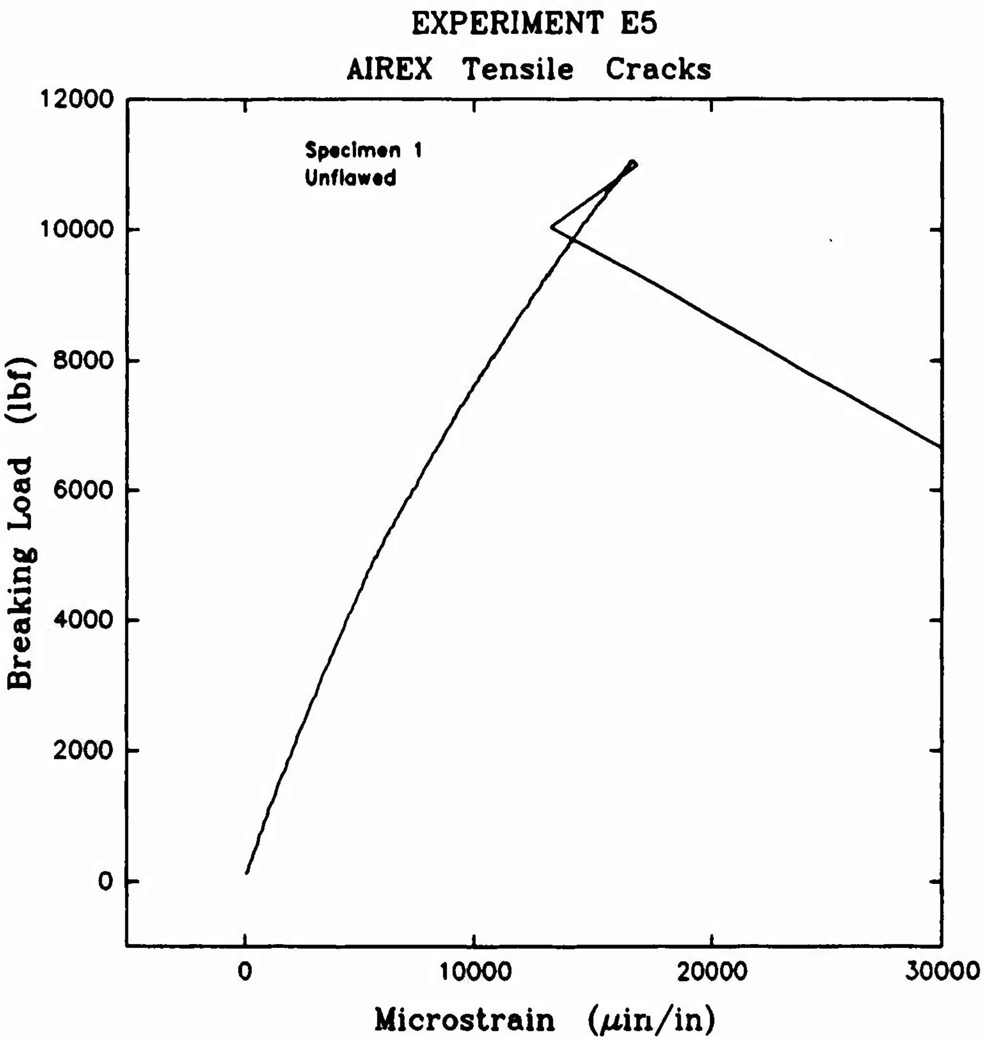
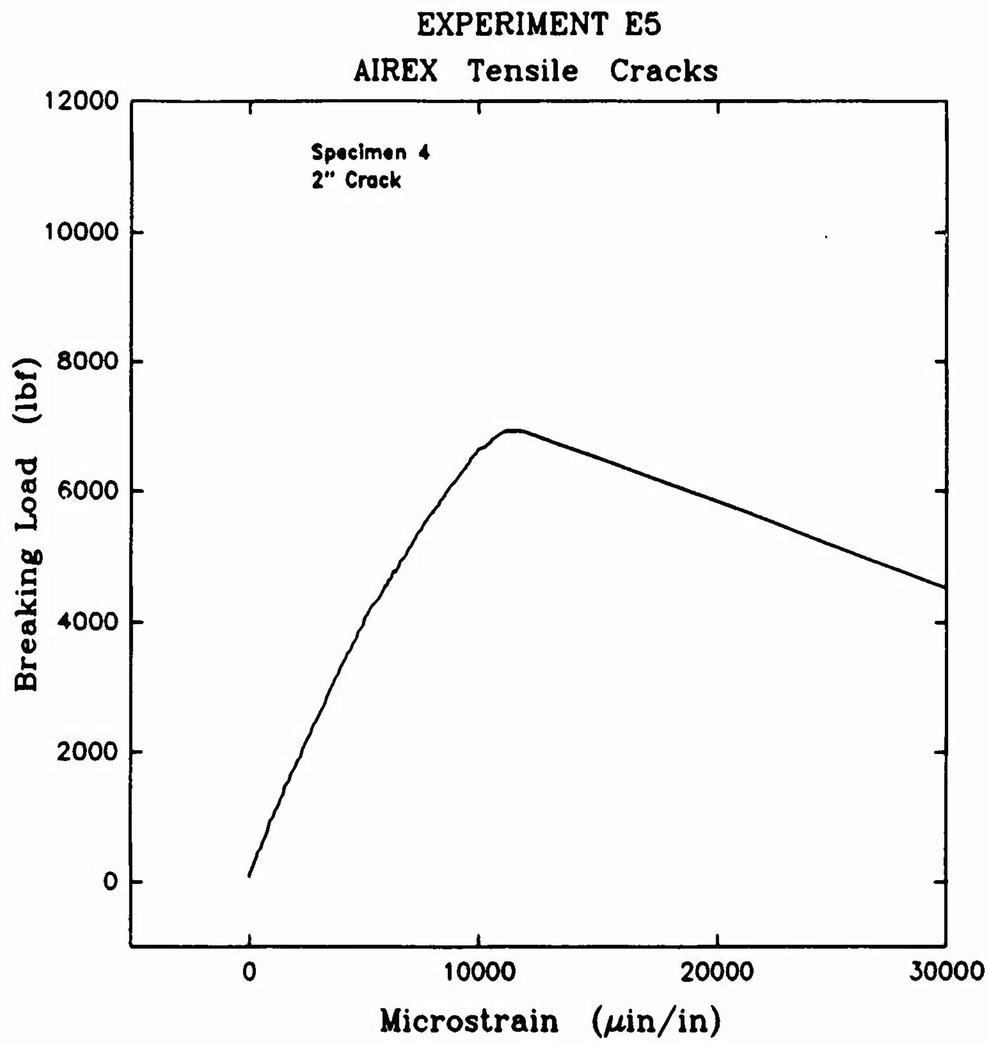

EXPERIMENT E5
AIREX Tensile Cracks
Specimen 1
Unflawed
Breaking Load (lbf)
Microstrain (μin/in)
12000
10000
8000
6000
4000
2000
0
0
10000
20000
30000

Figure C3-3



EXPERIMENT E5
AIREX Tensile Cracks
Specimen 4
2" Crack
12000
10000
8000
6000
4000
2000
0
Breaking Load (lbf)
0
10000
20000
30000
Microstrain (μin/in)

Figure C3-4

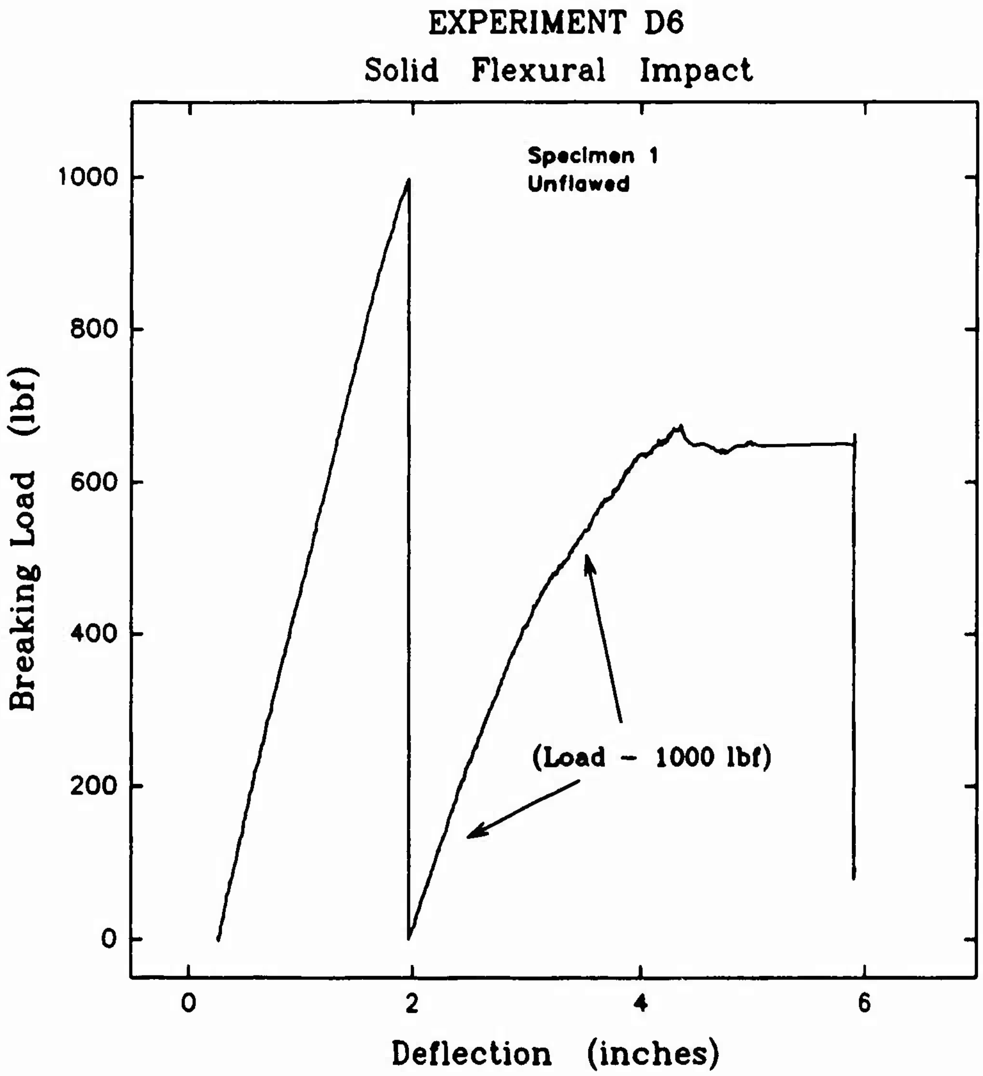


Figure C3-5

The y axes in this and the following plots are folded at 1000 lbf. That part of the plot line beyond 1000 lbf is the continuation of the first part. The ordinates after the fold are displayed as 1000 lbf less than the actual values. This reflects the way in which the testing machine and the data recording equipment logged the experimental data and has been retained for compactness of display.

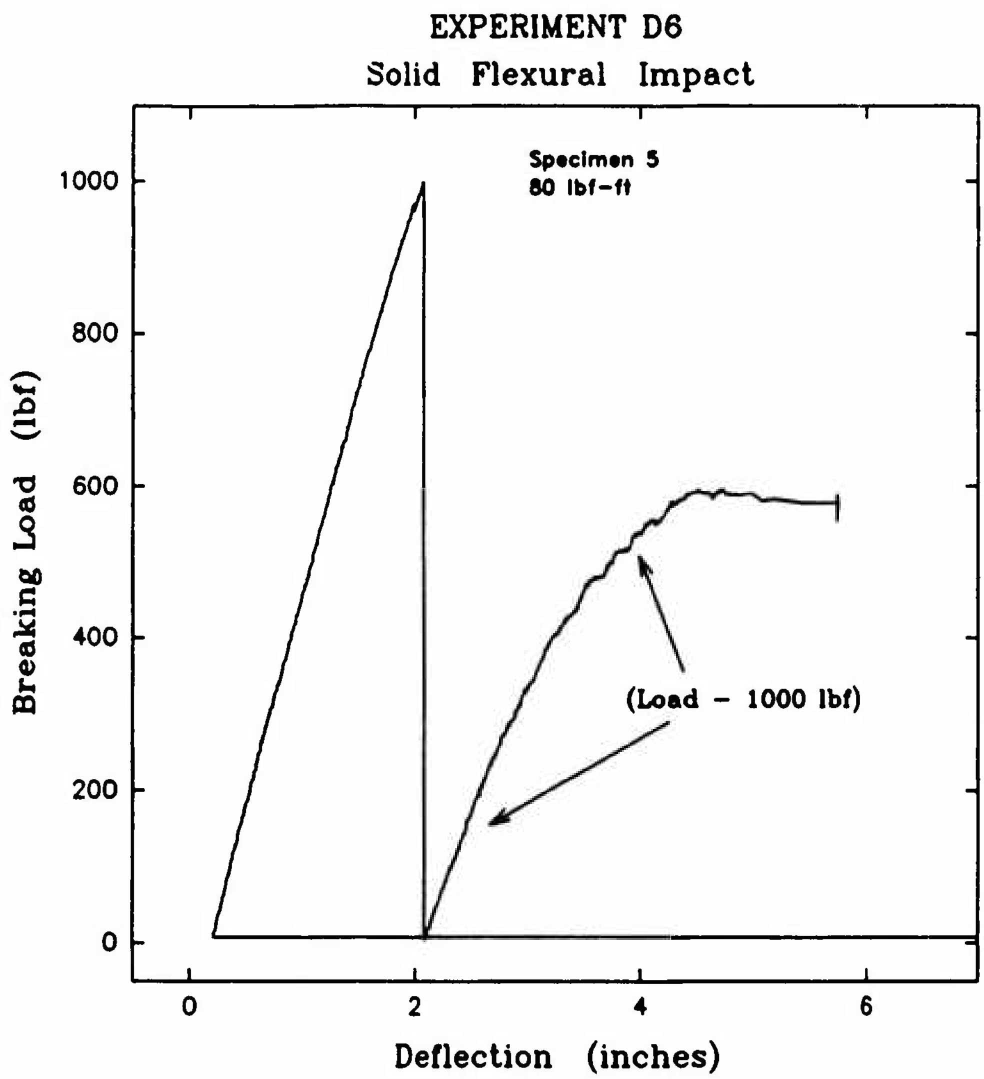
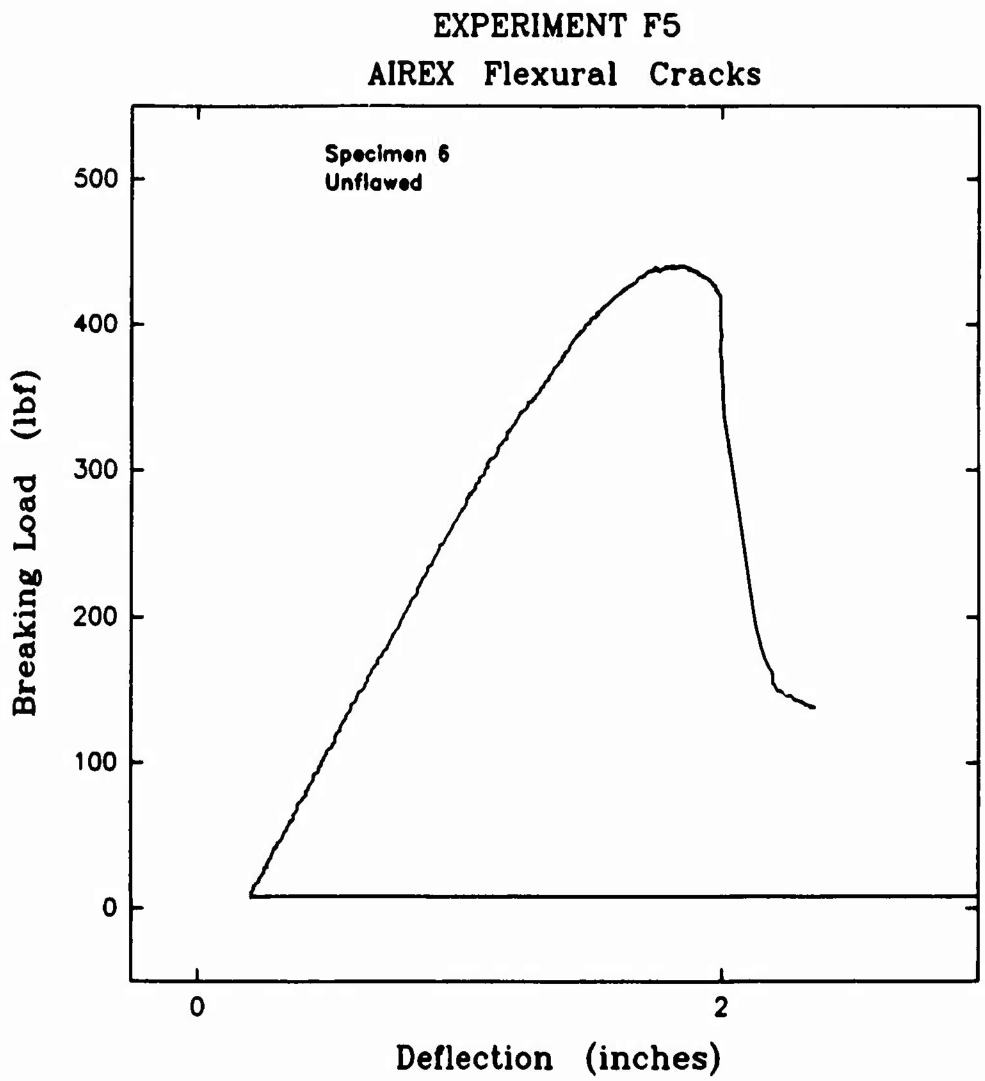
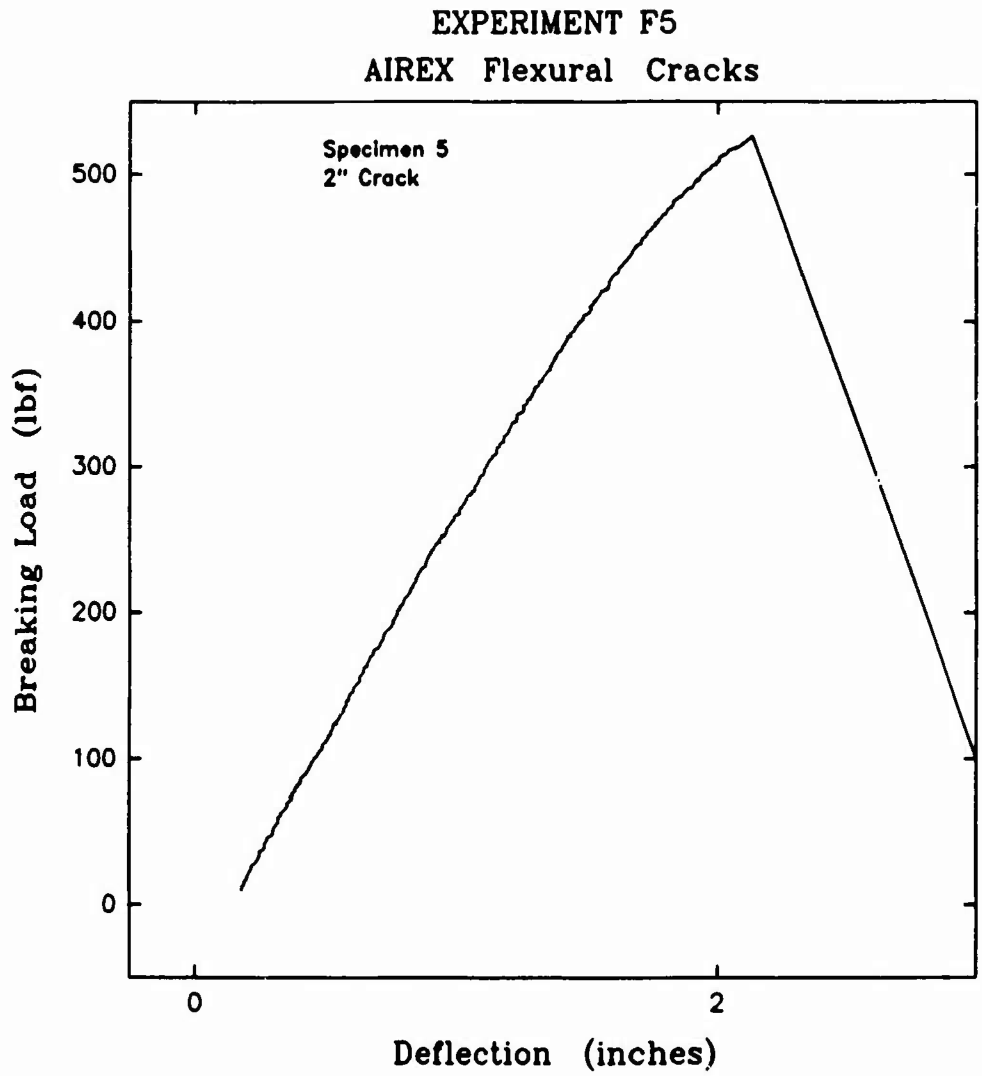

EXPERIMENT D6
Solid Flexural Impact
Specimen 5
80 lbf-ft
Breaking Load (lbf)
1000
800
600
400
200
0
(Load - 1000 lbf)
0
2
4
6
Deflection (inches)

Figure C3-6



EXPERIMENT F5
AIREX Flexural Cracks
Specimen 6
Unflawed
500
400
300
200
100
0
Breaking Load (lbf)
0
2
Deflection (inches)

Figure C3-7



EXPERIMENT F5
AIREX Flexural Cracks
Specimen 5
2" Crack
Breaking Load (lbf)
500
400
300
200
100
0
0
2
Deflection (inches)

Figure C3-8

C4 Analysis Plots - Defect Size Experiments

Figures C4-1 through C4-70 show strength (breaking load per unit specimen width) vs. defect size for each individual experiment, comparing defect sizes for various defect and core types and for both tensile and flexural testing. The data points are shown, and regression lines are fitted to the data. For experiments in which there is only one defect size other than unflawed specimens, the regression line is a least squares straight line. For experiments having more than two defect sizes including unflawed, the regression line is a least squares parabola. Figures 21 through 55 are for tensile experiments, Figures 56 through 90 are for Flexural experiments.

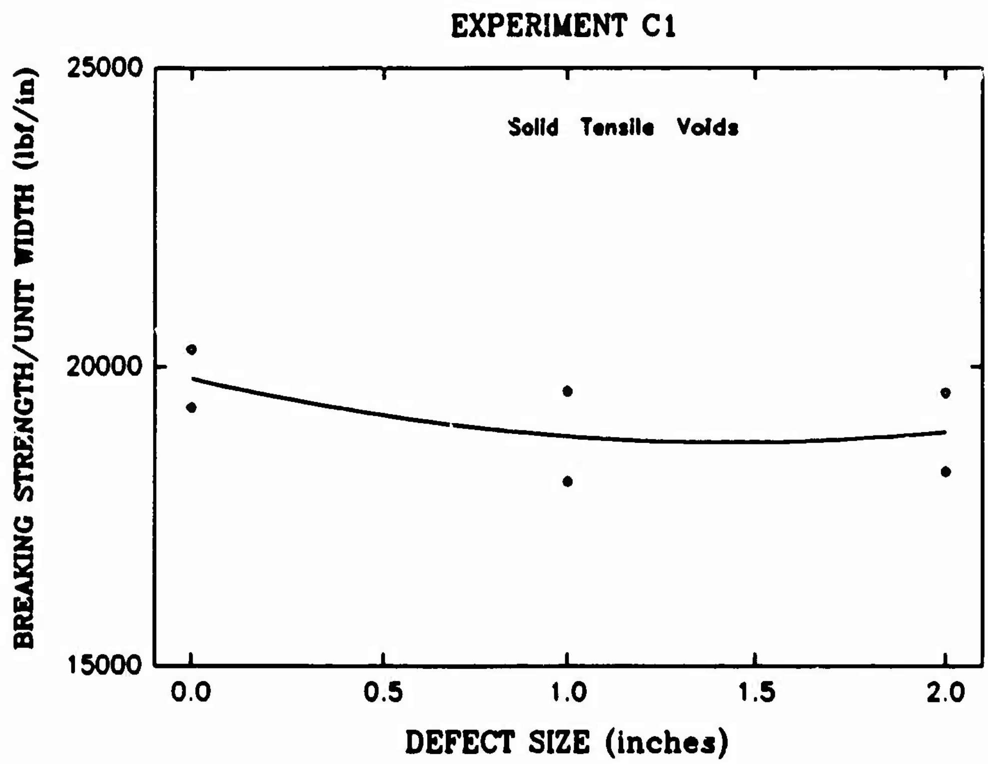


Figure C4-1

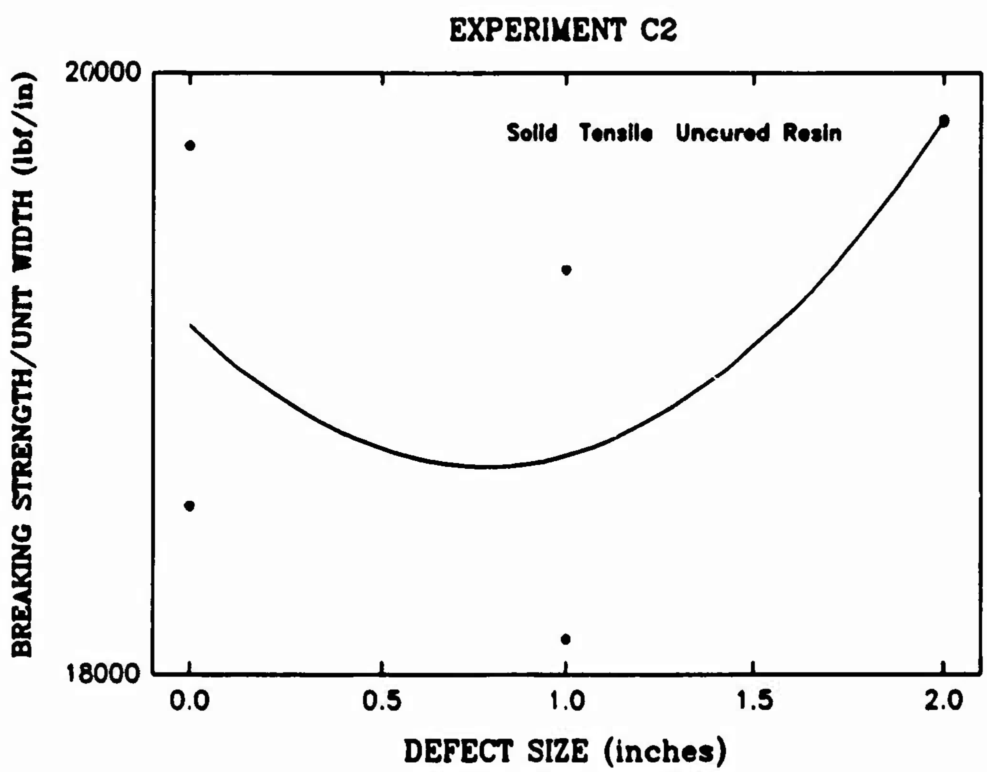


Figure C4-2

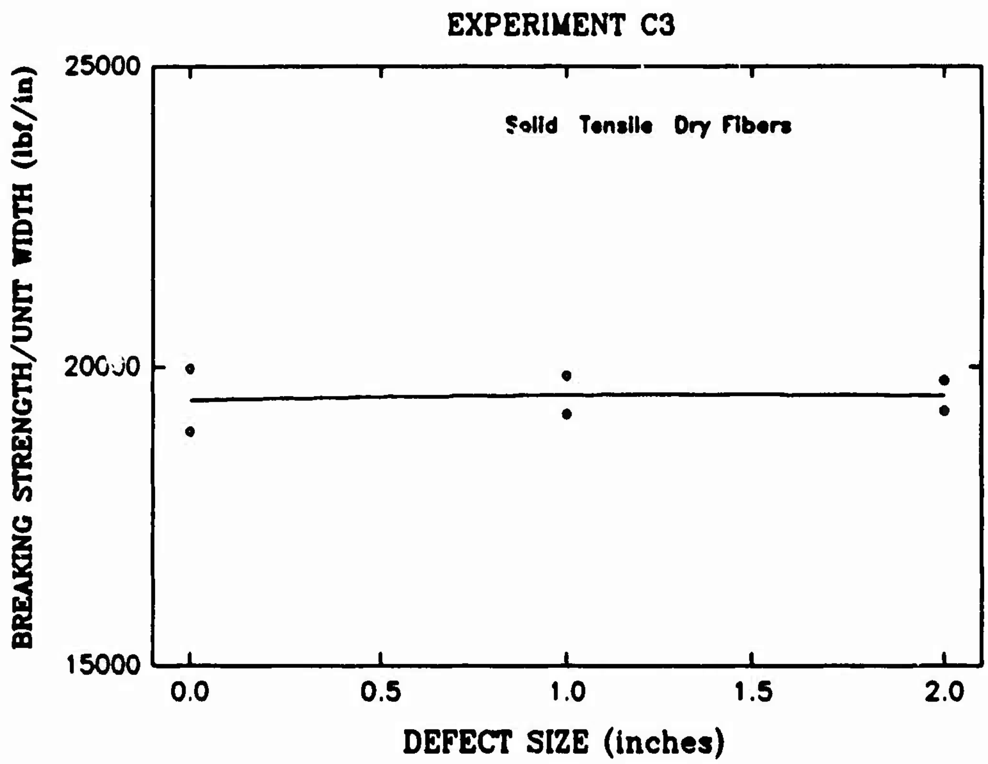


Figure C4-3

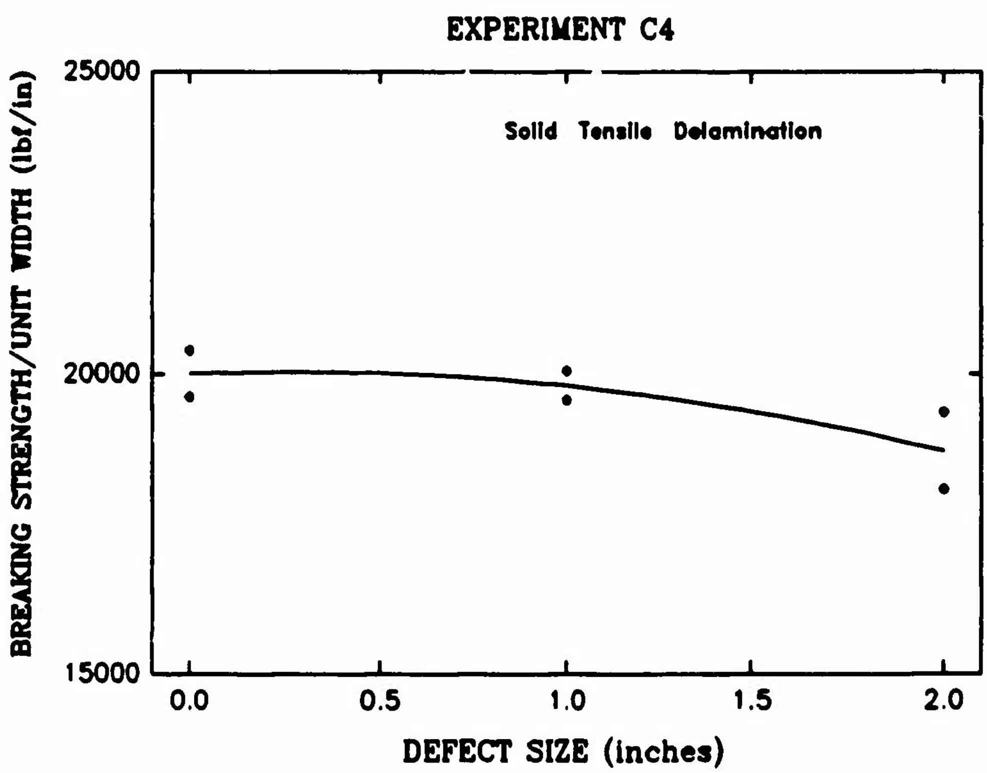


Figure C4-4

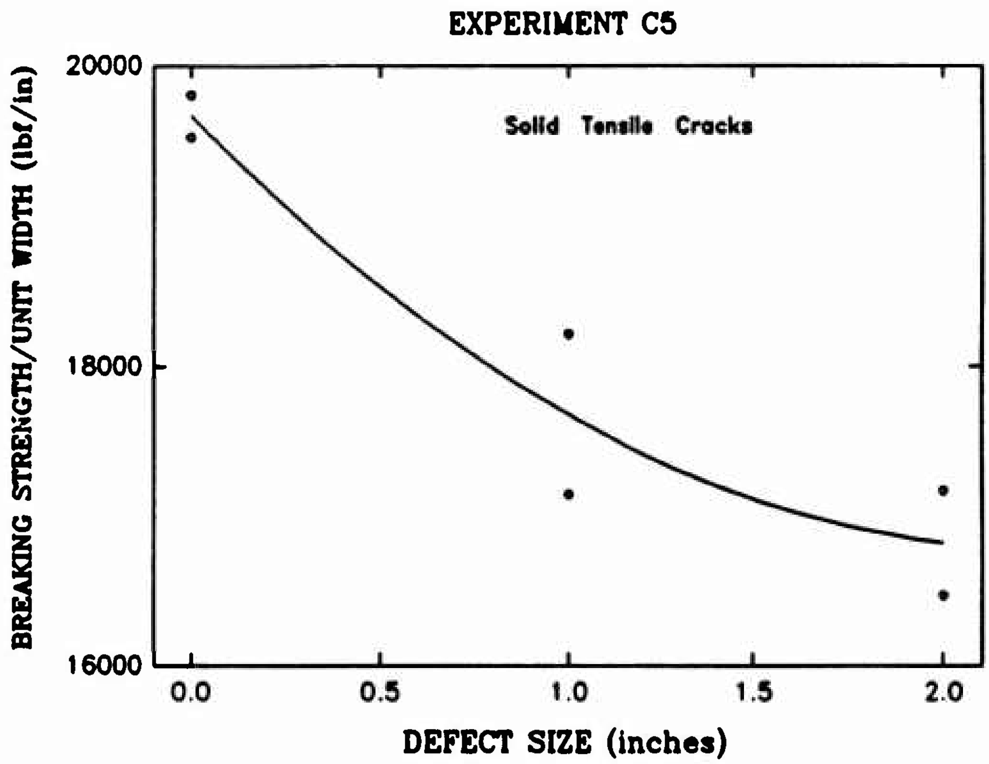


Figure C4-5

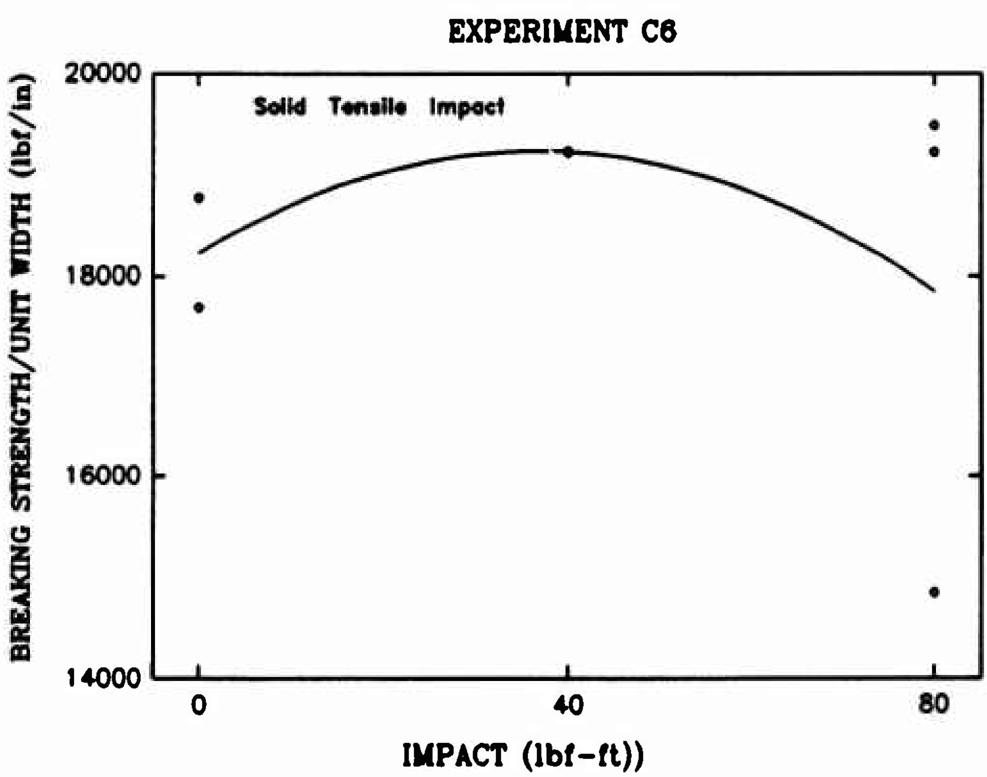


Figure C4-6

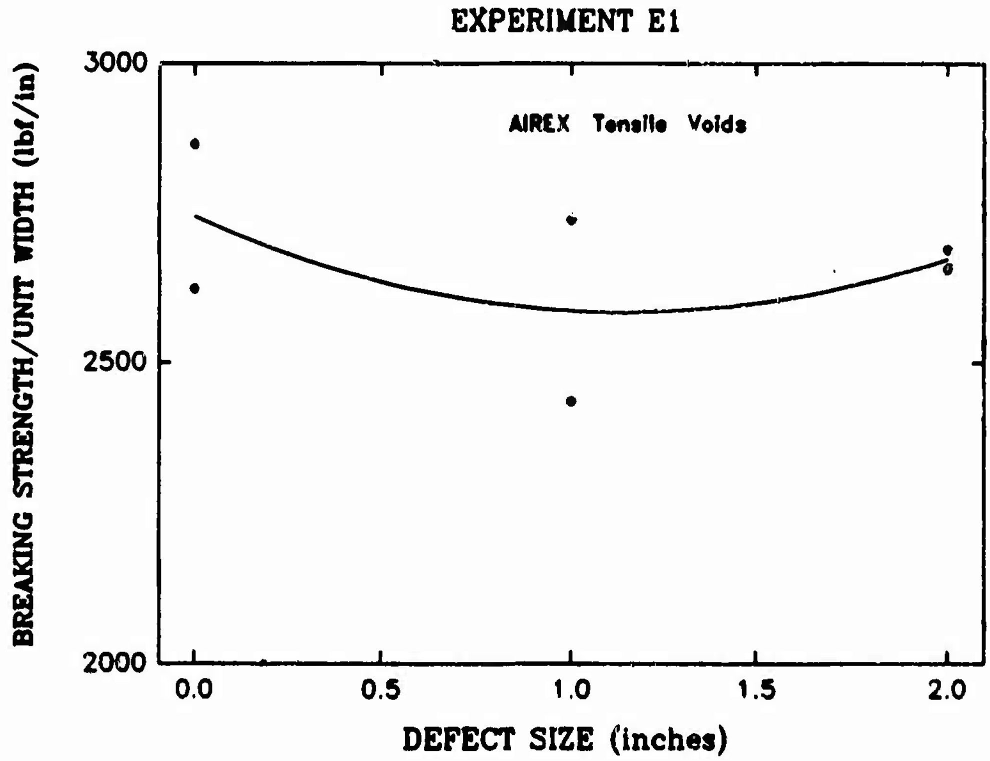


Figure C4-7

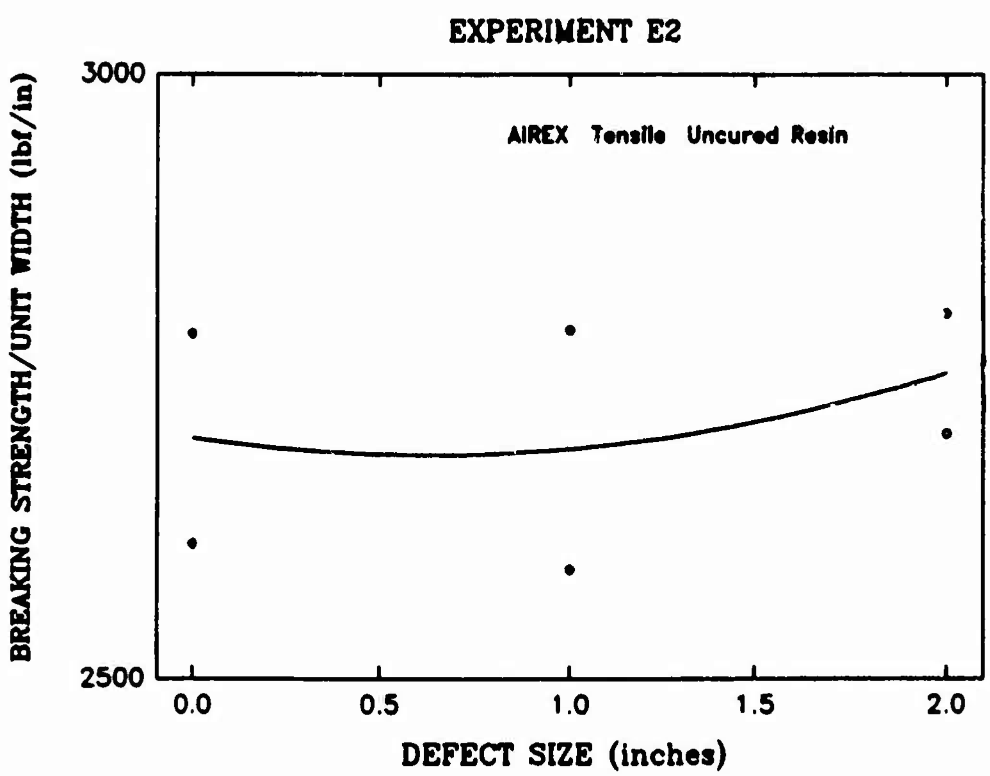


Figure C4-8

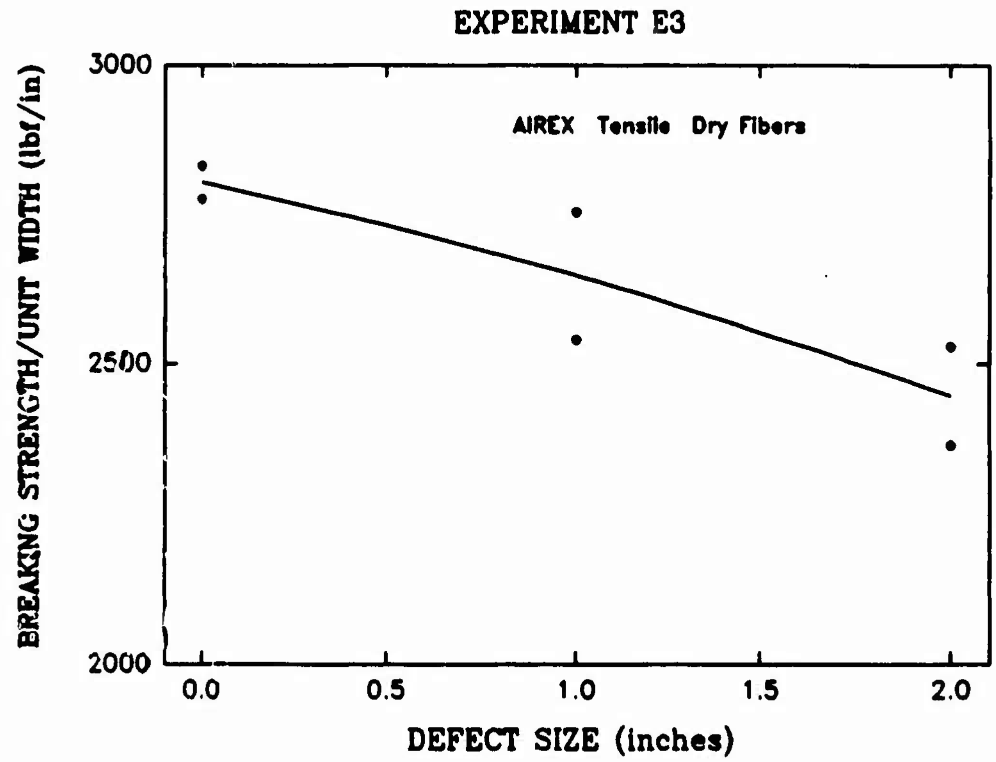


Figure C4-9

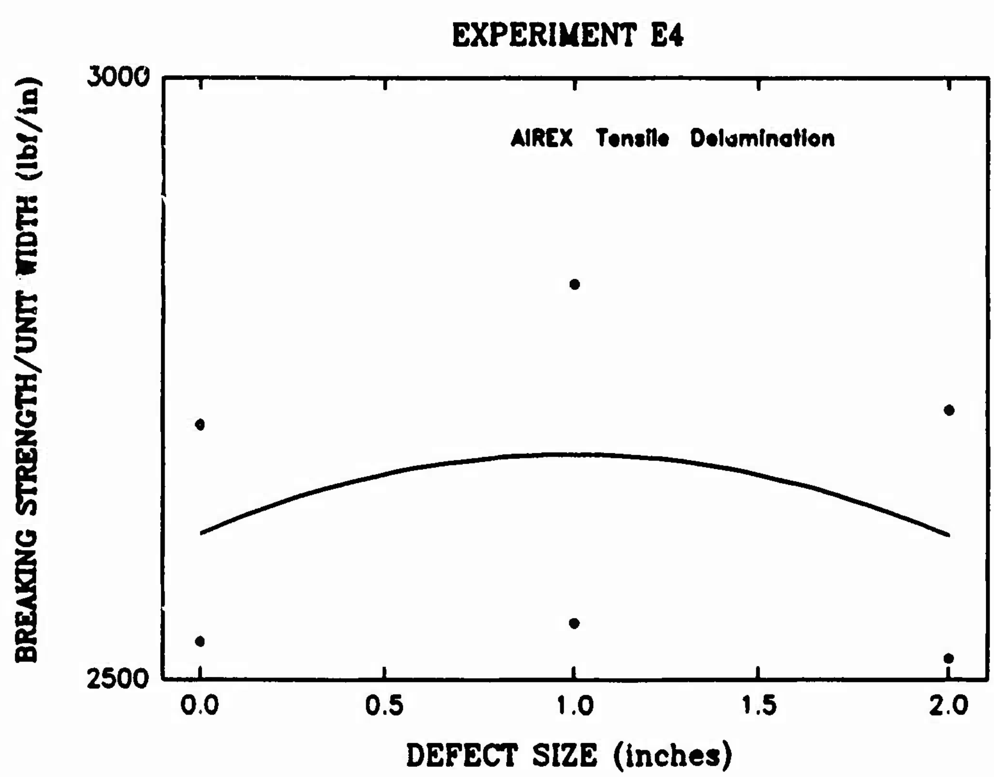


Figure C4-10

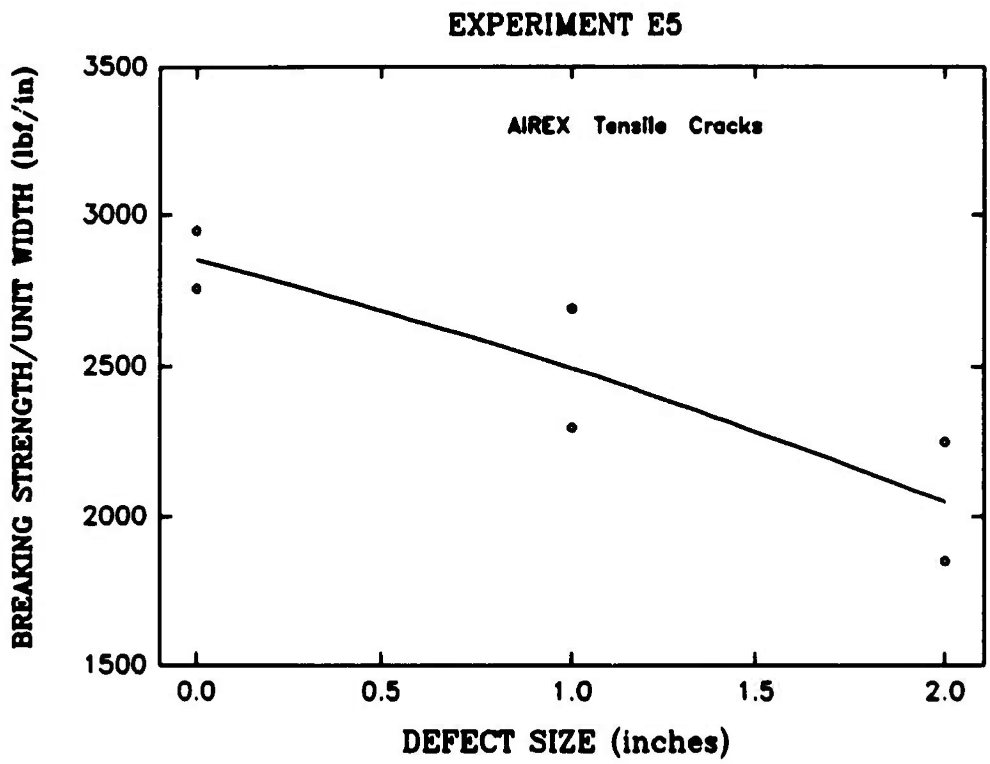


Figure C4-11

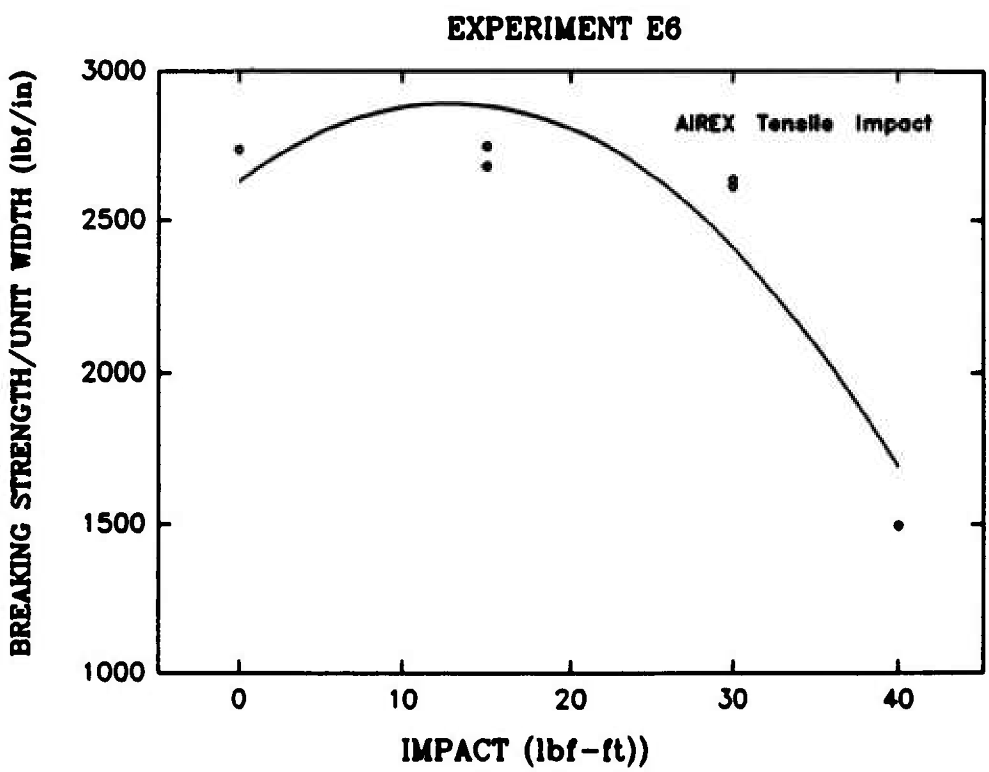


Figure C4-12

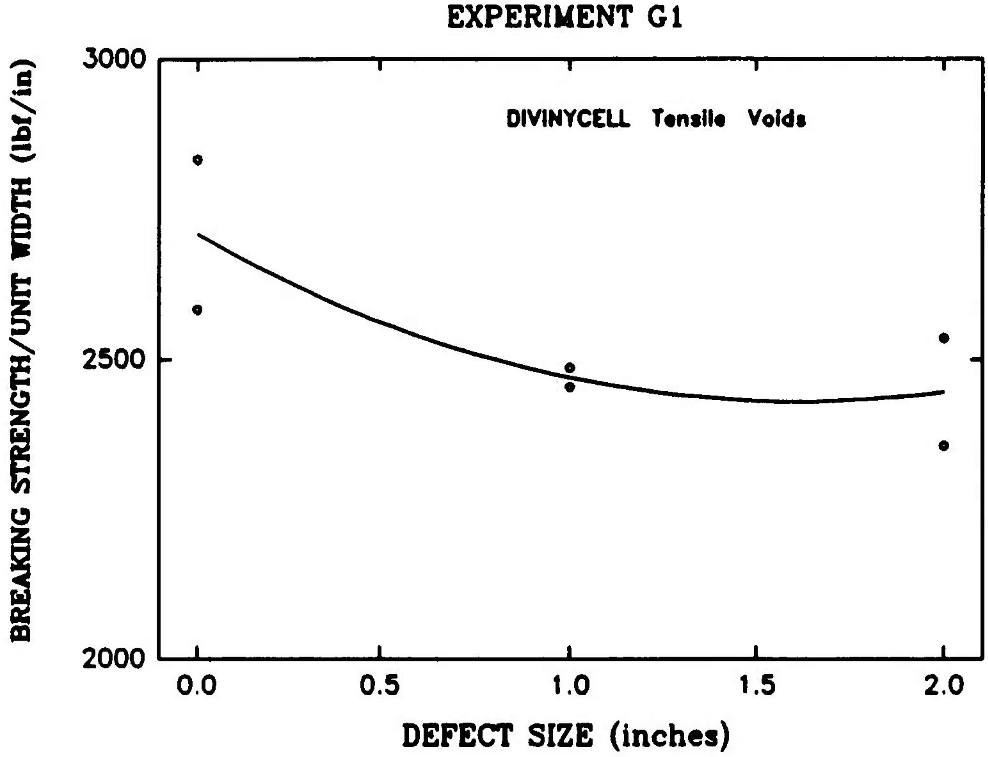


Figure C4-13

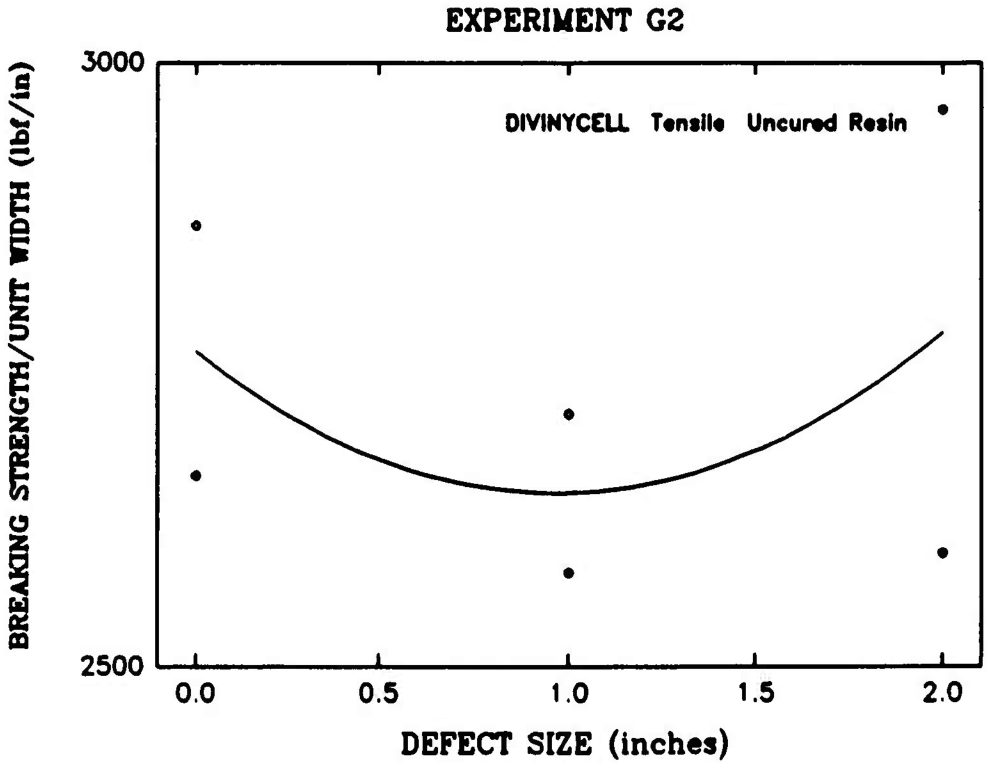


Figure C4-14

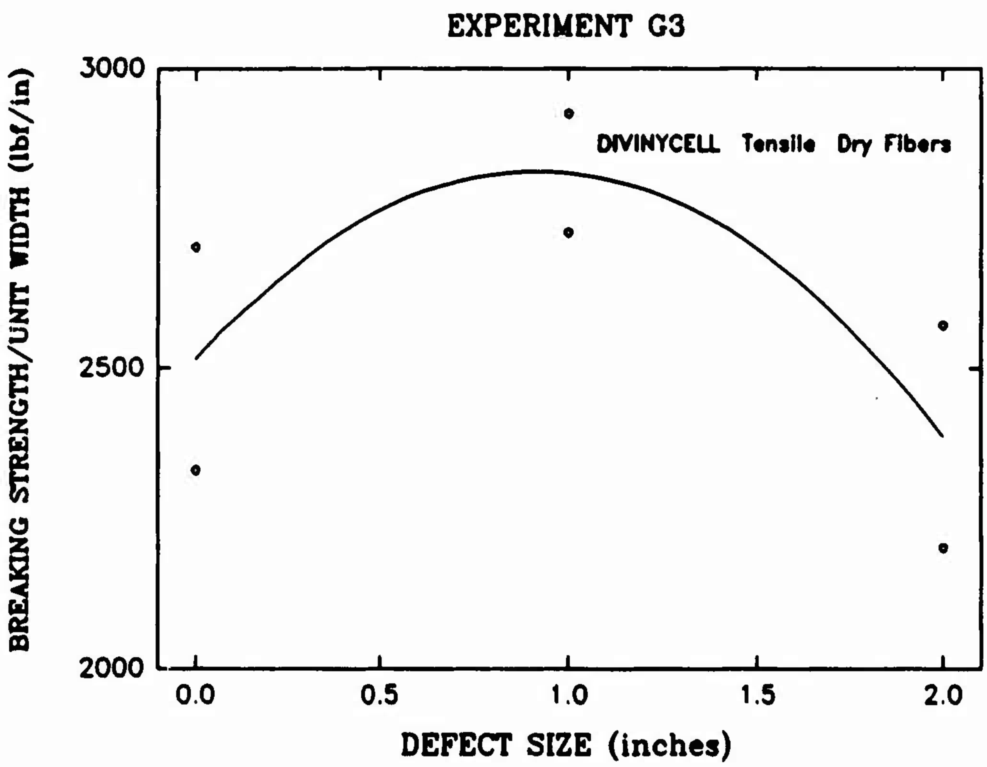


Figure C4-15

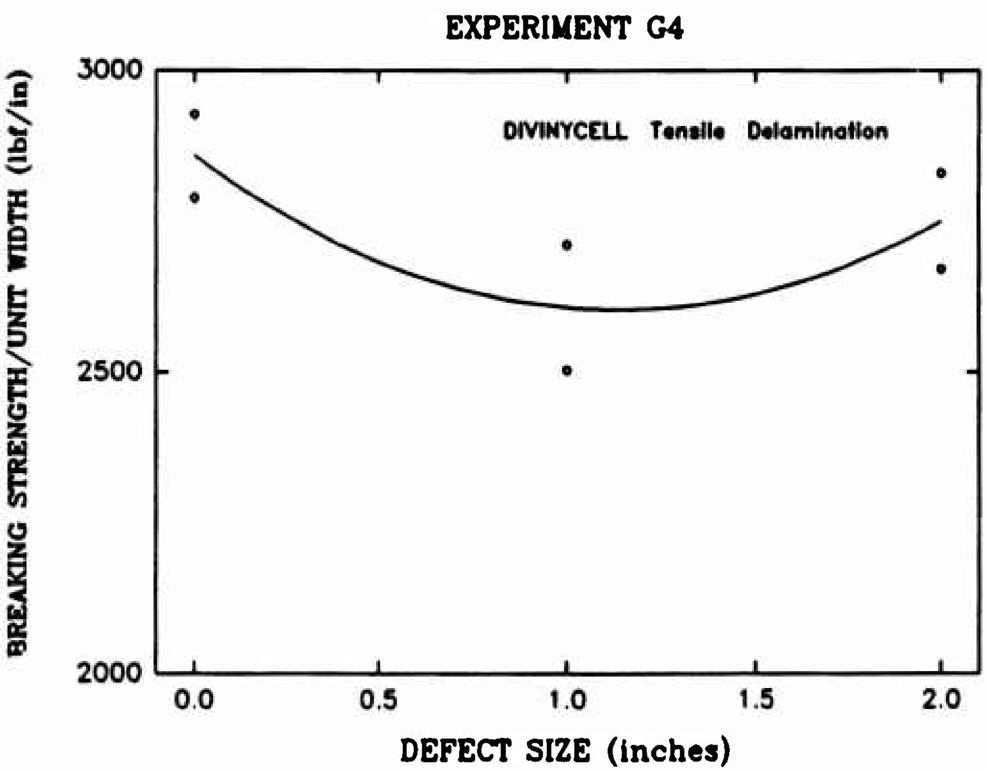


Figure C4-16

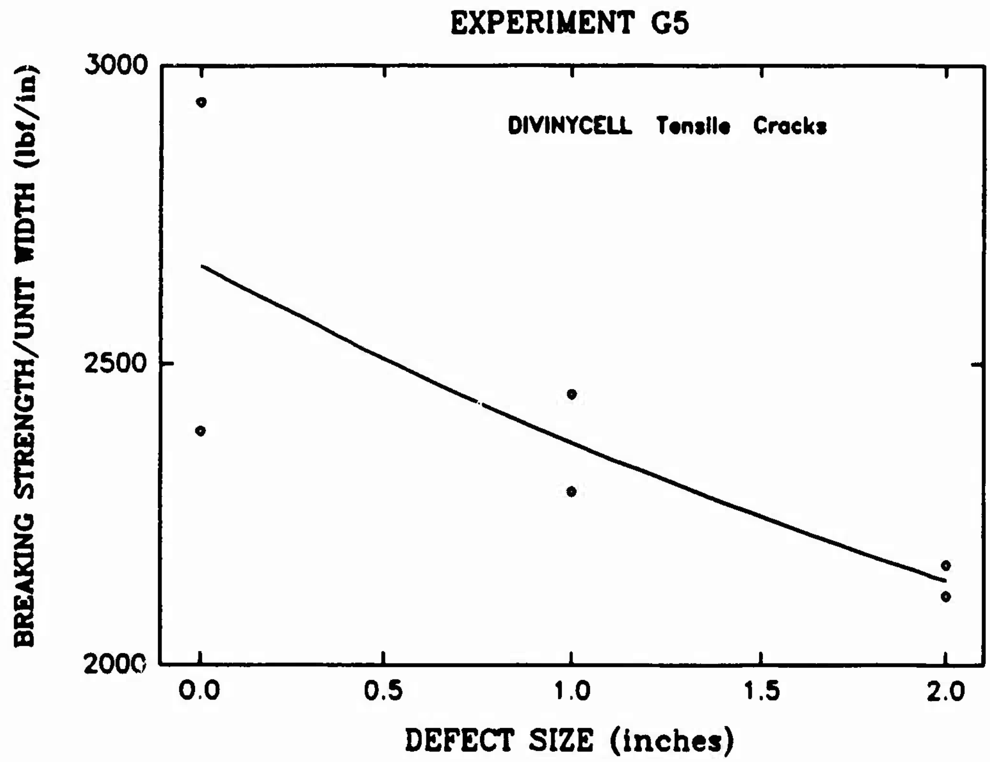


Figure C4-17

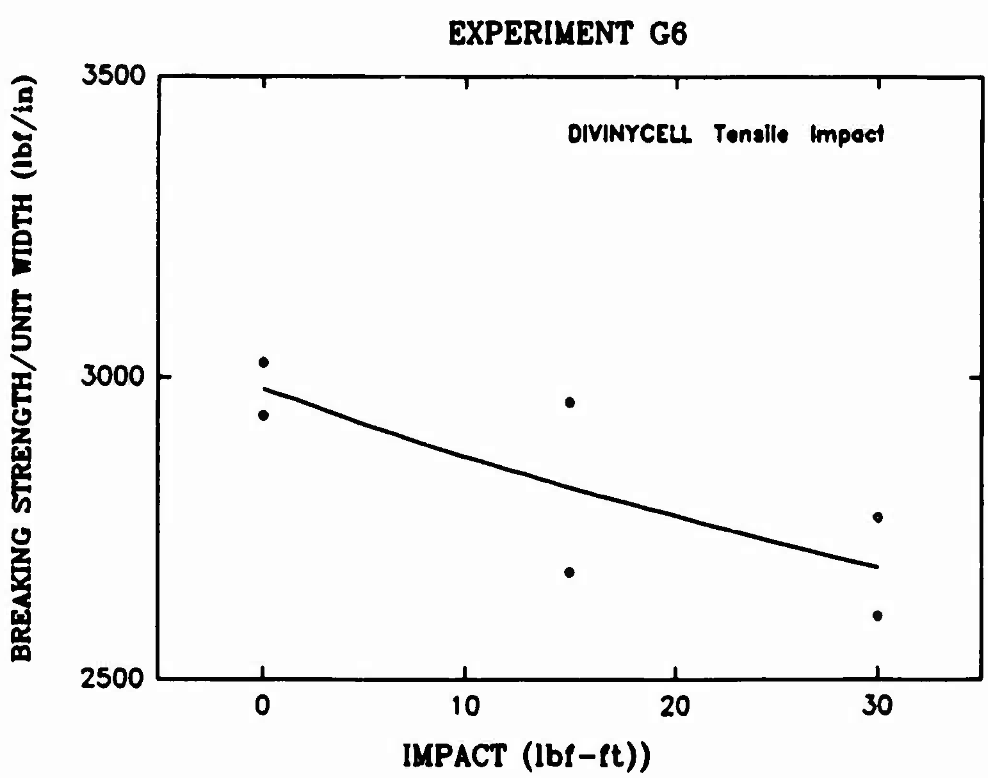


Figure C4-18

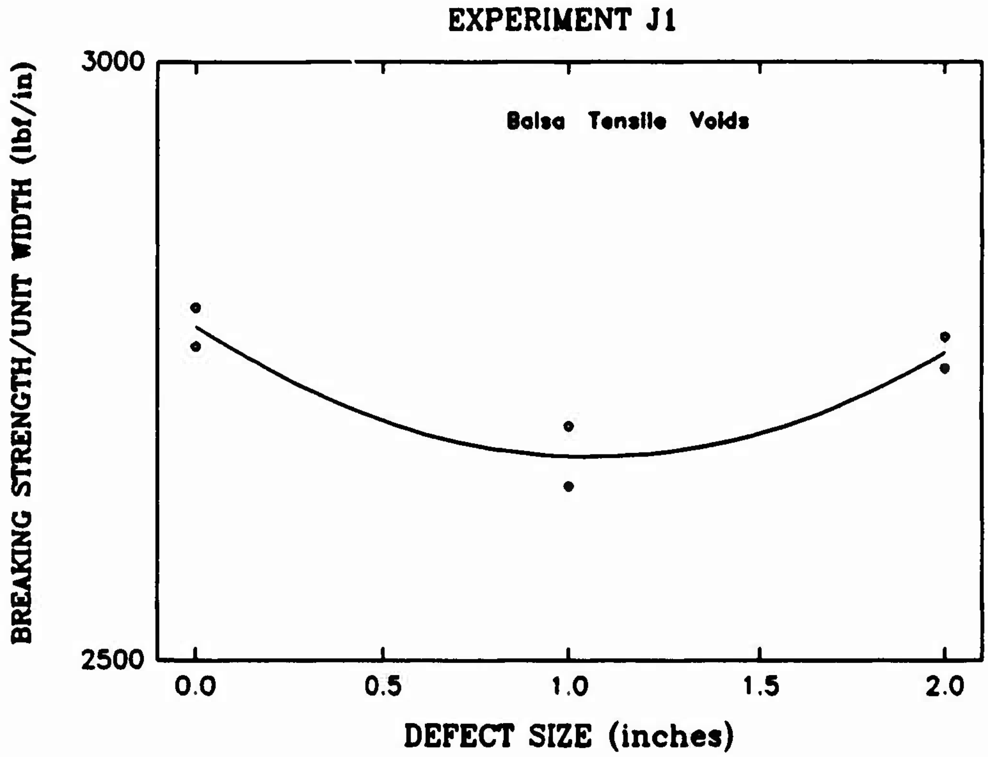


Figure C4-19

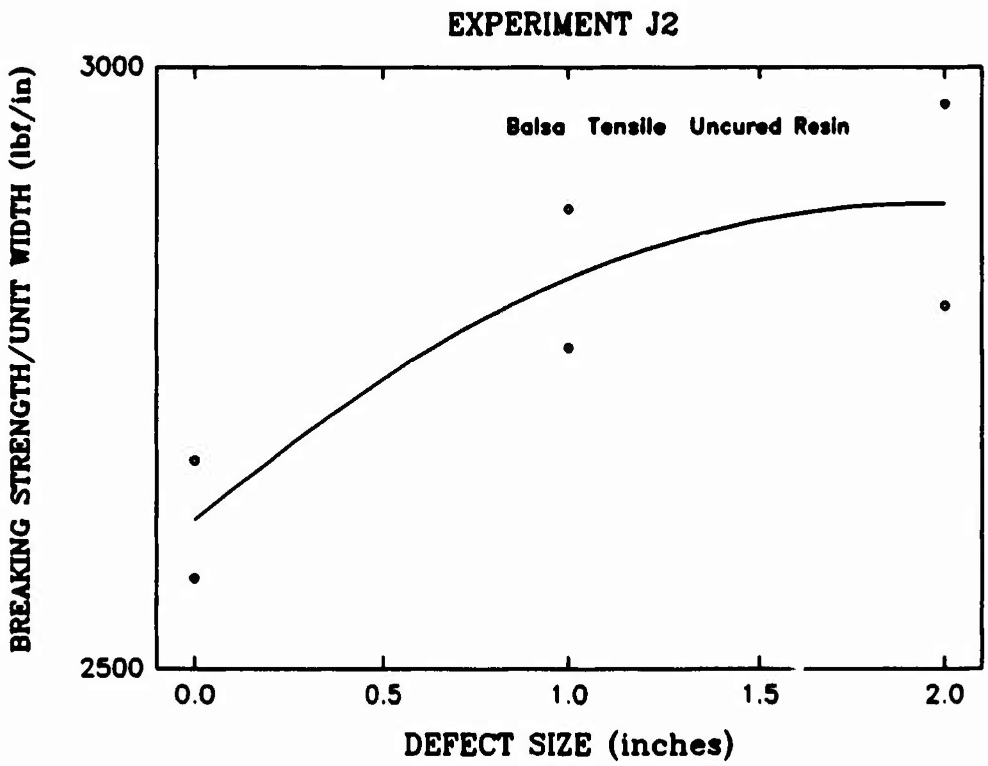


Figure C4-20

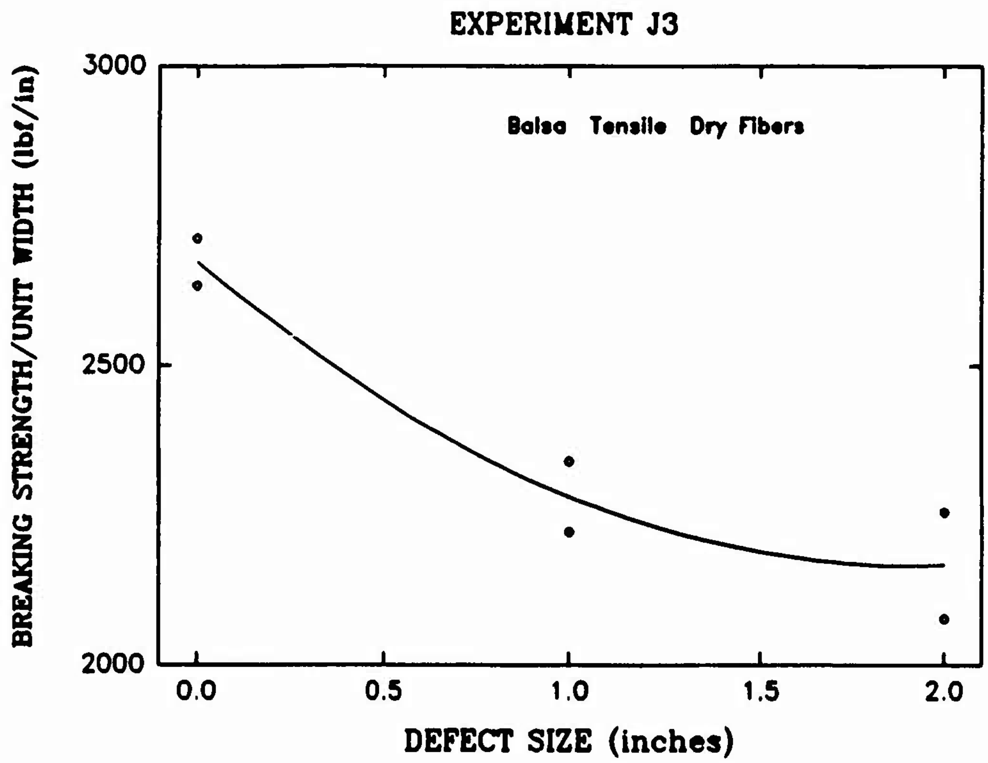


Figure C4-21

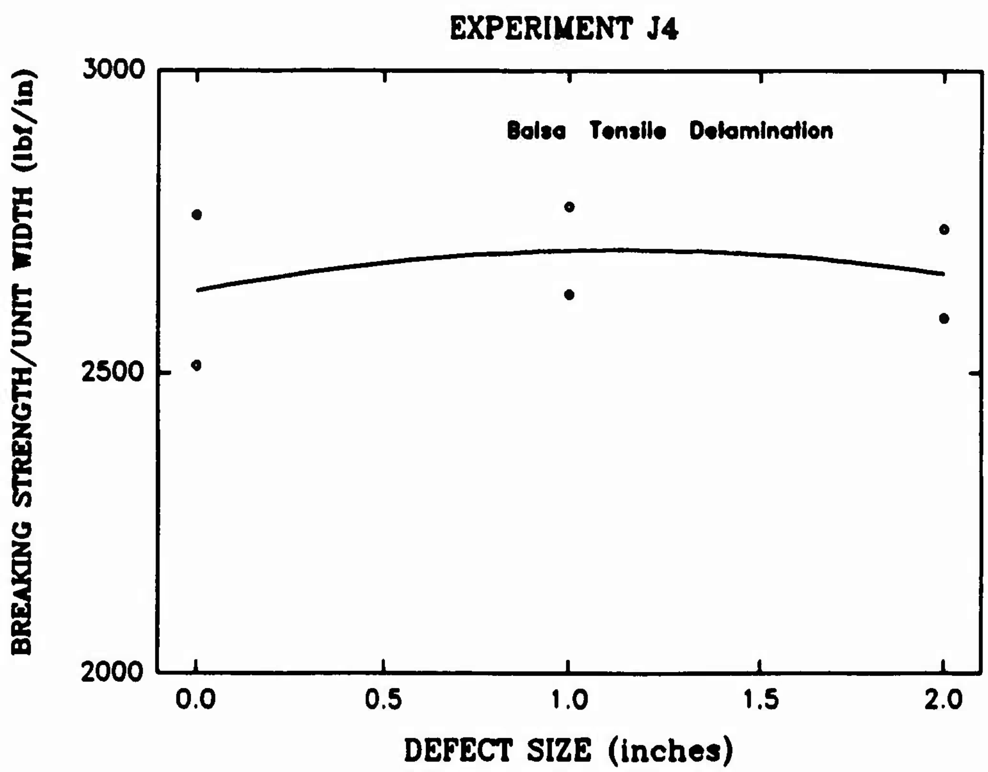


Figure C4-22

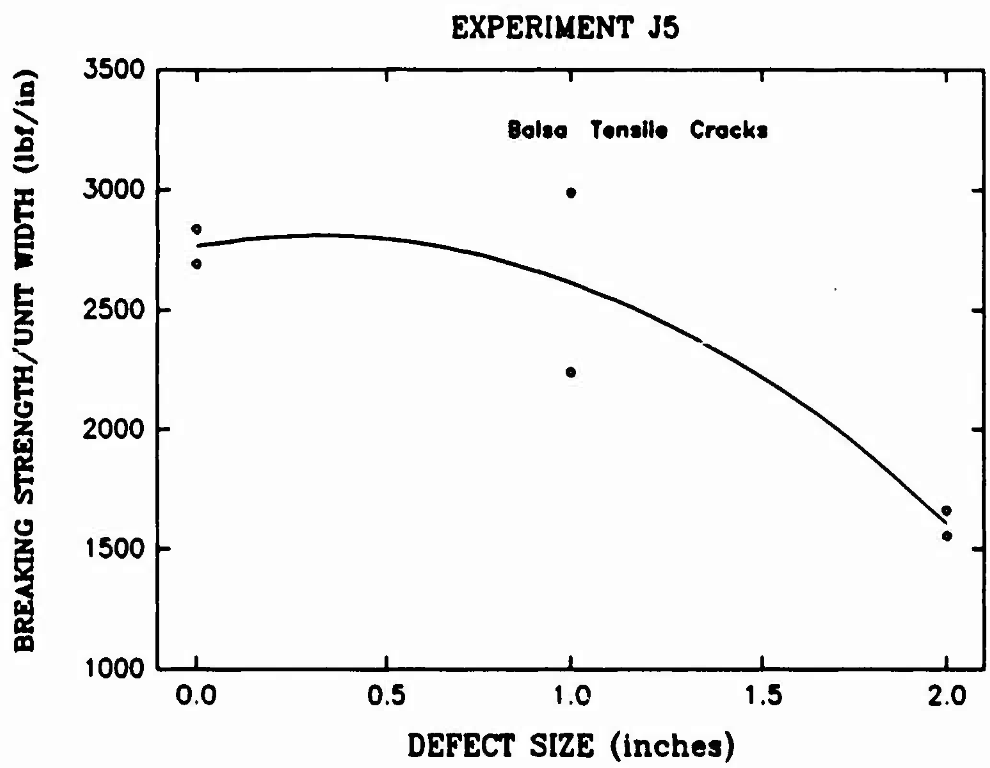


Figure C4-23

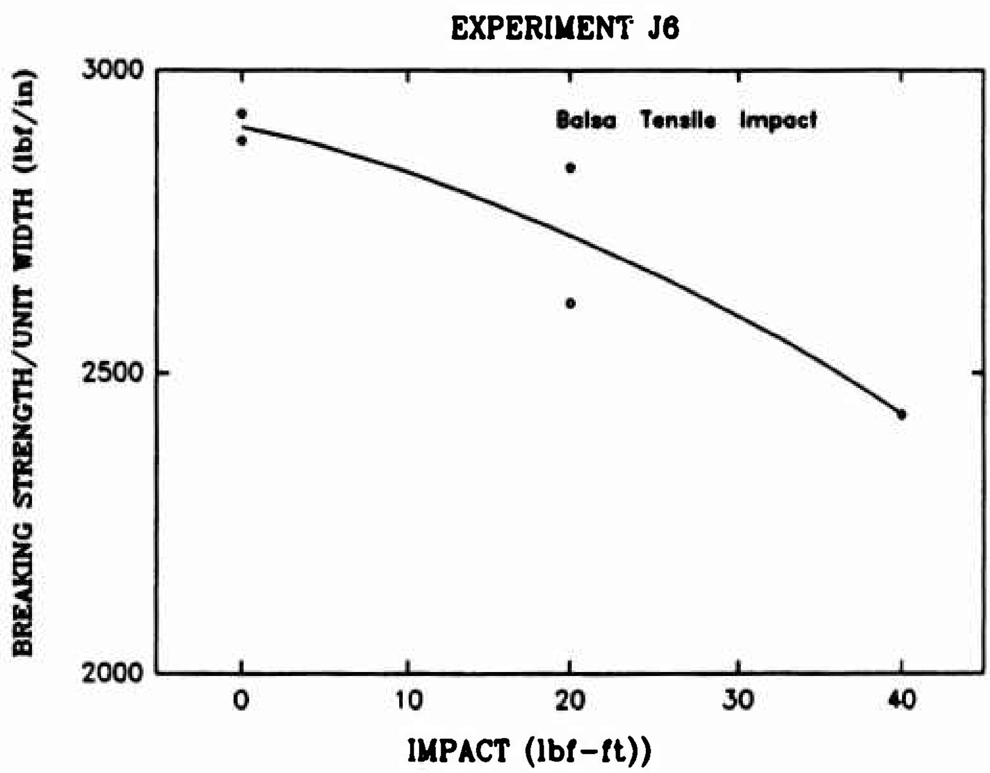


Figure C4-24

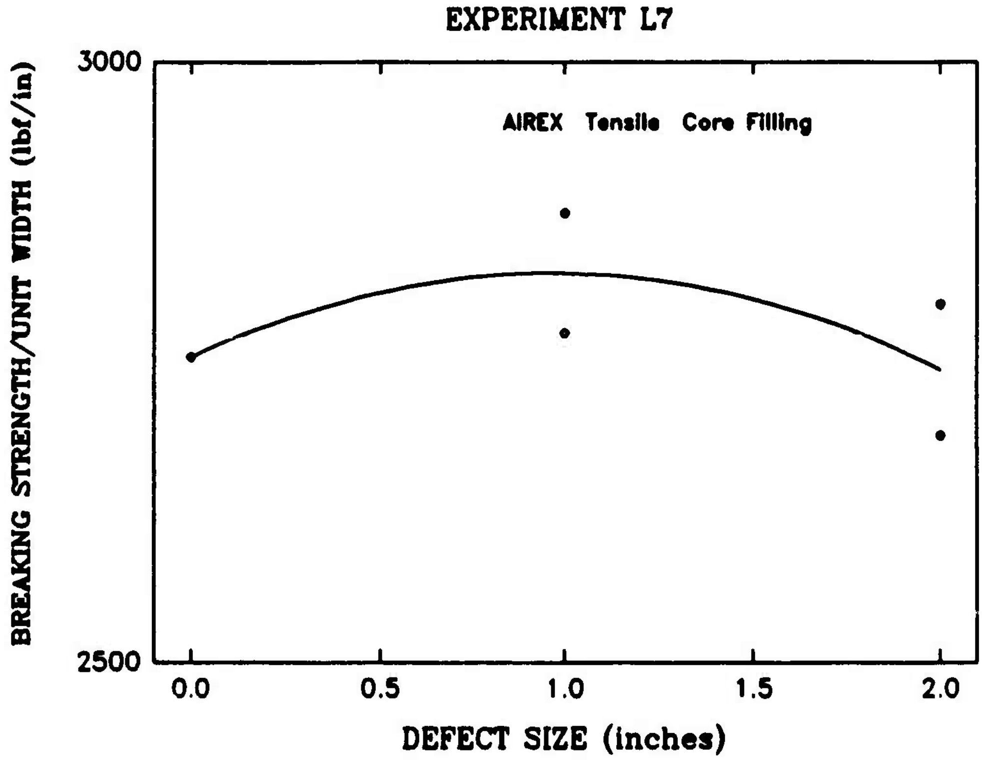


Figure C4-25

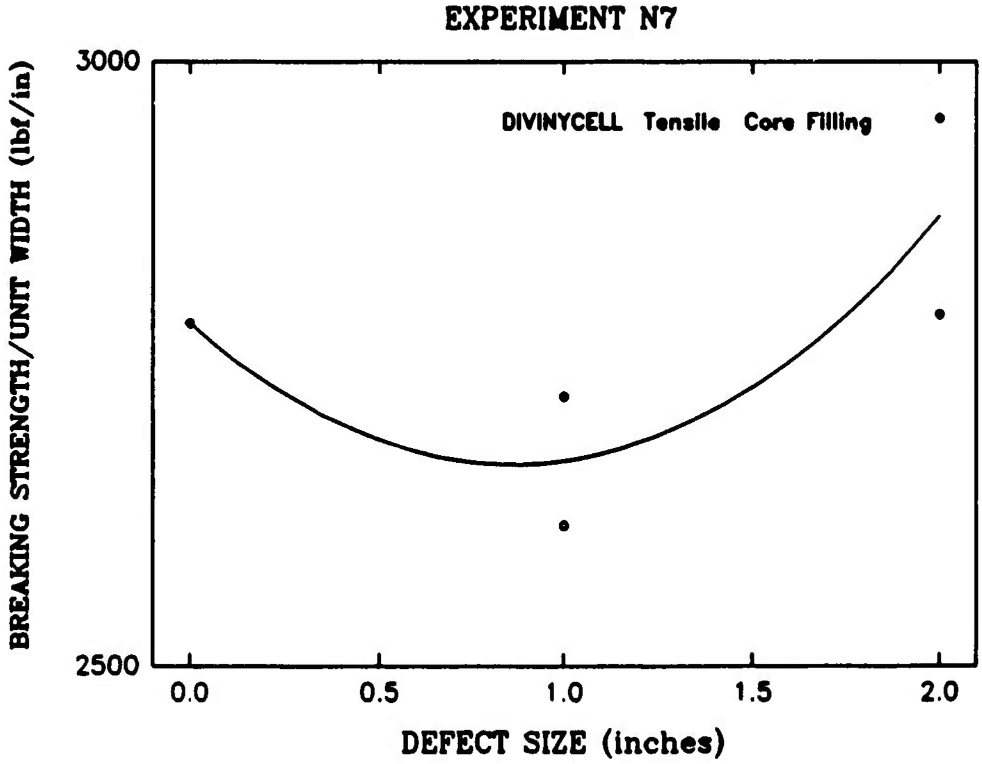
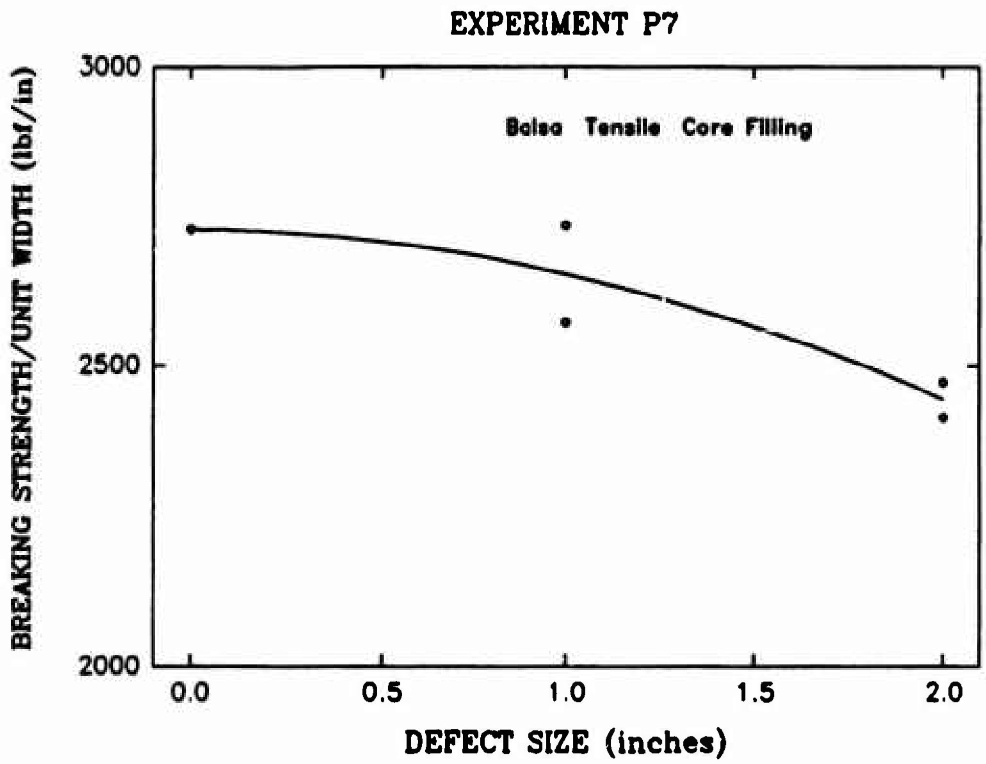


Figure C4-26



EXPERIMENT P7
Balsa Tensile Core Filling
BREAKING STRENGTH/UNIT WIDTH (lbf/in)
3000
2500
2000
0.0
0.5
1.0
1.5
2.0
DEFECT SIZE (inches)

Figure C4-27

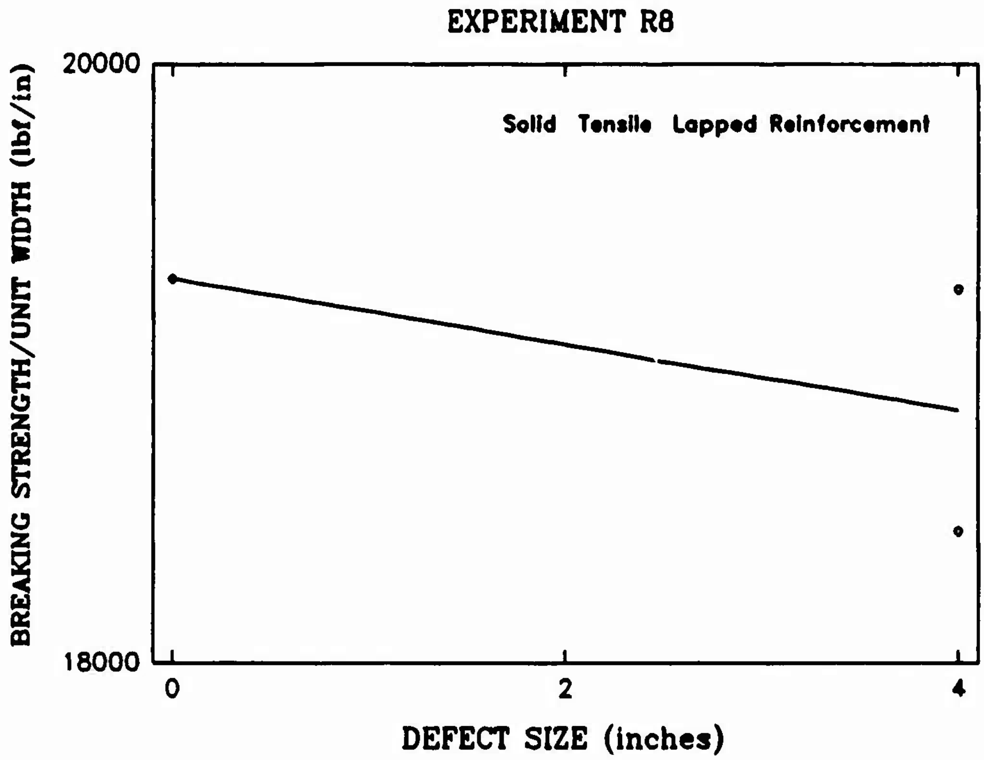


Figure C4-28

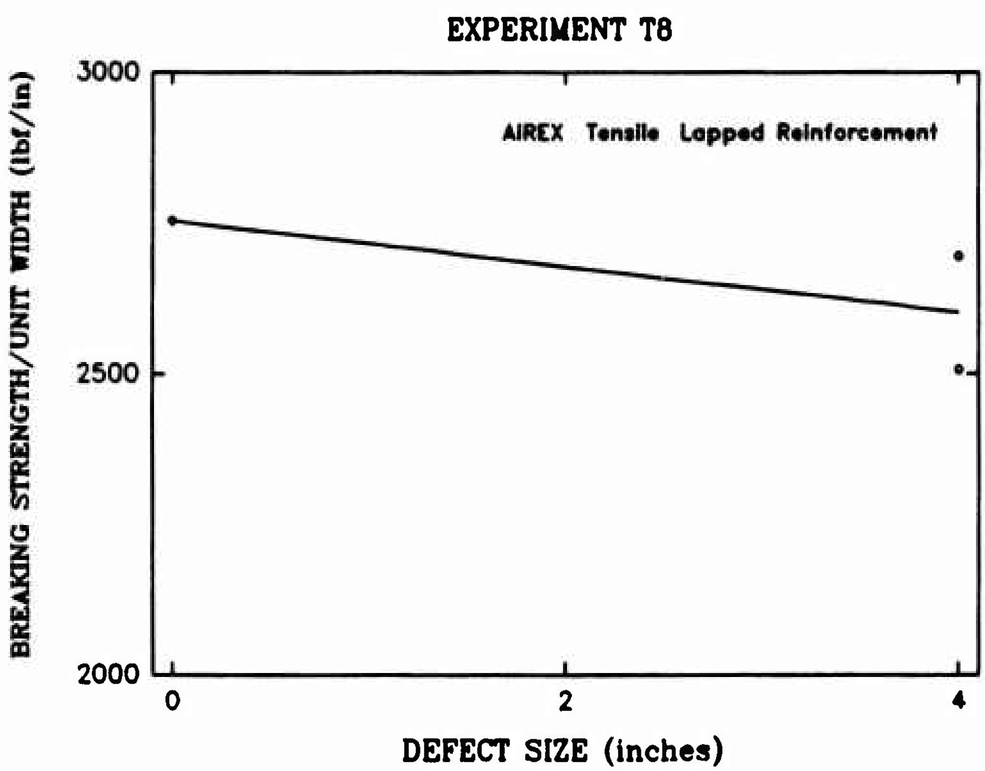


Figure C4-29

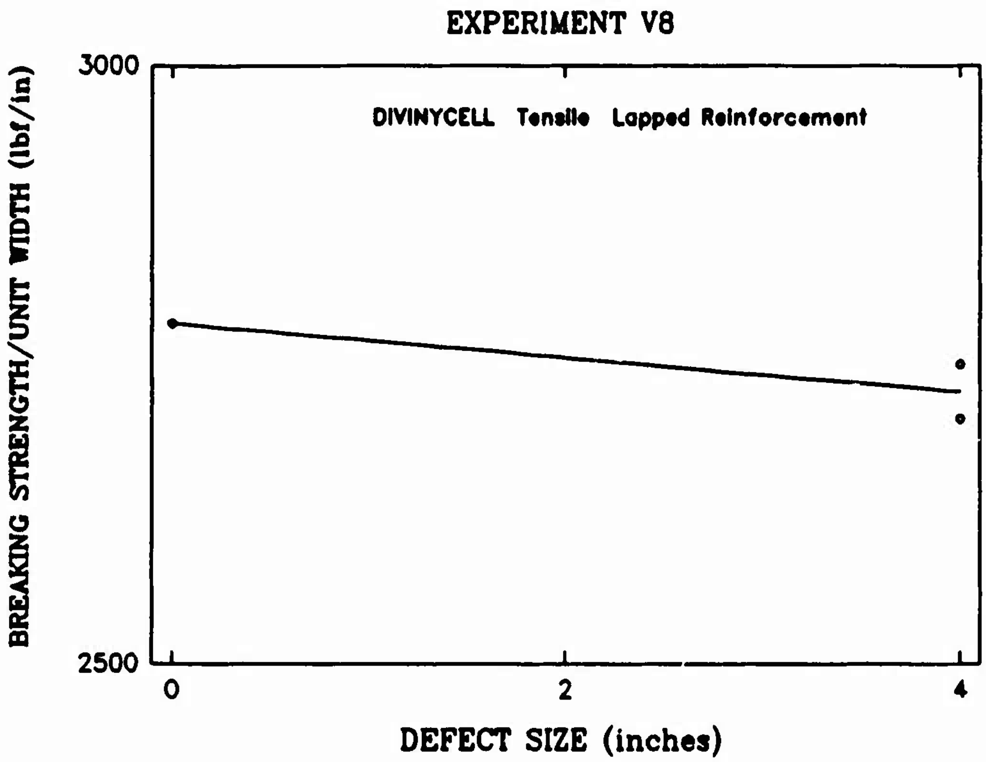


Figure C4-30

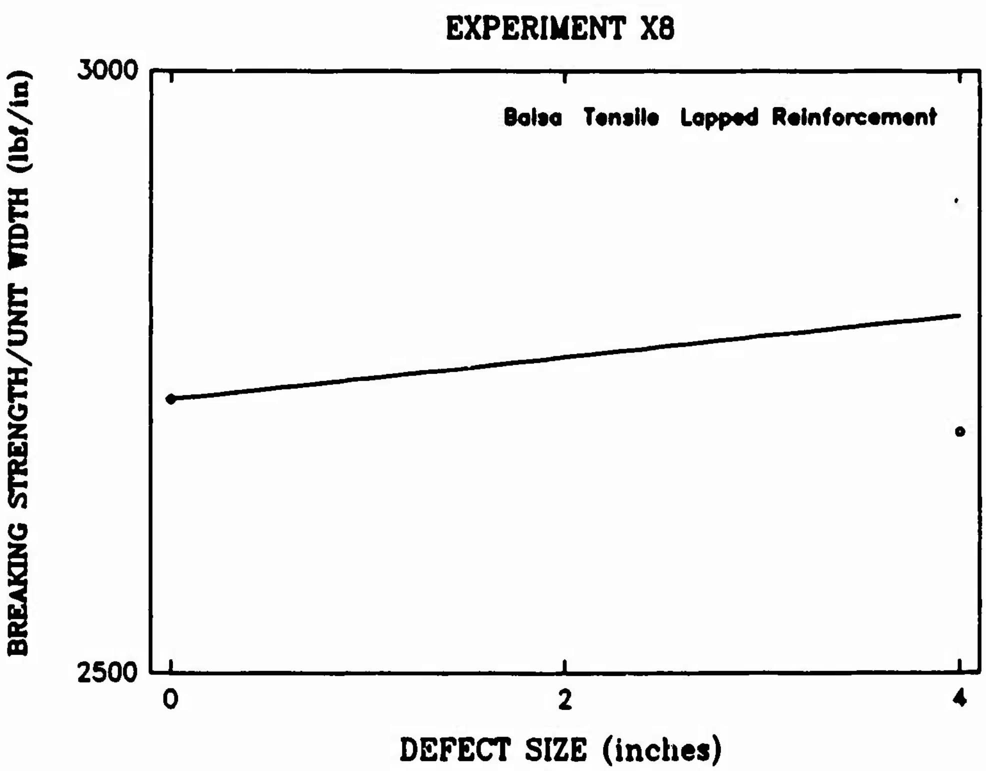


Figure C4-31

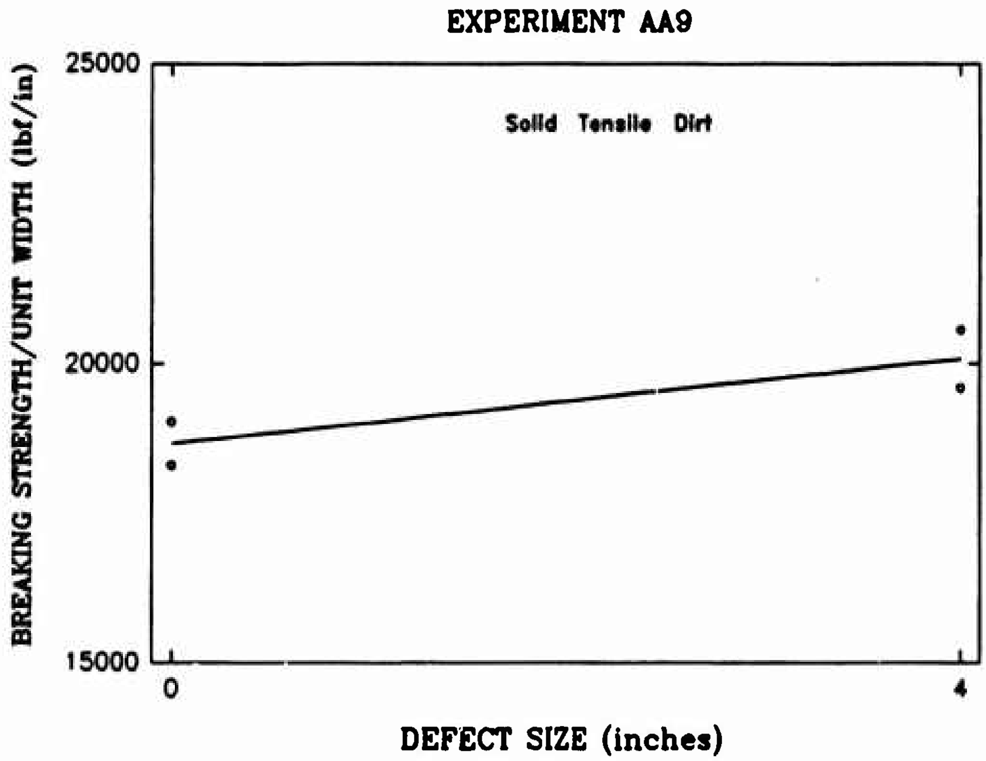


Figure C4-32

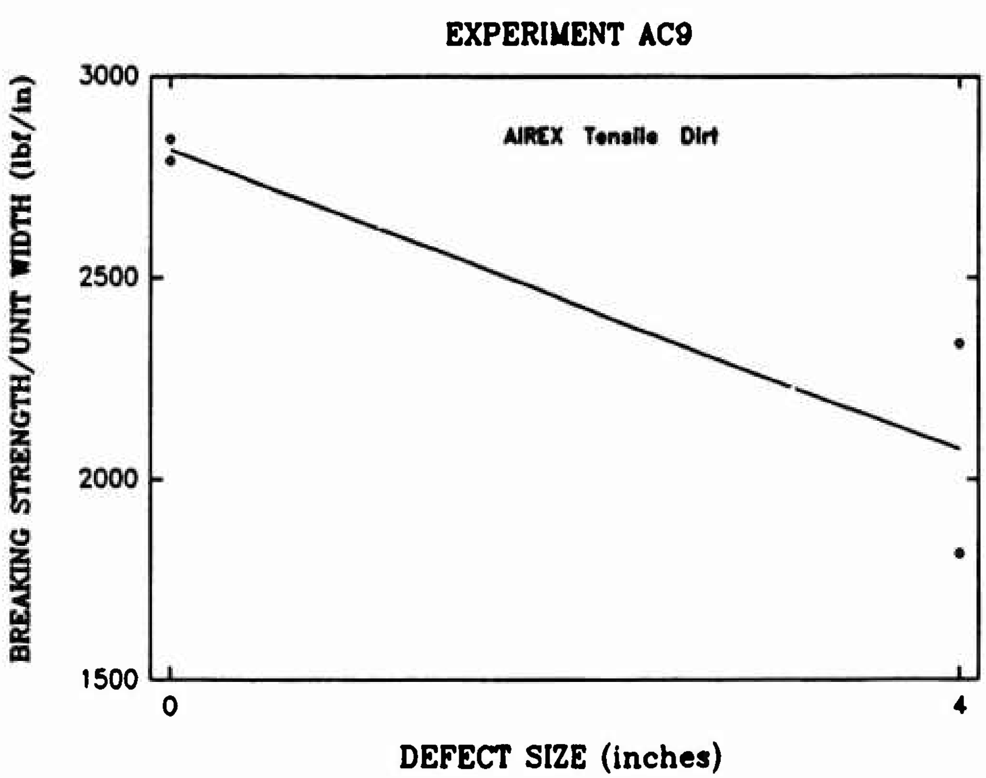


Figure C4-33

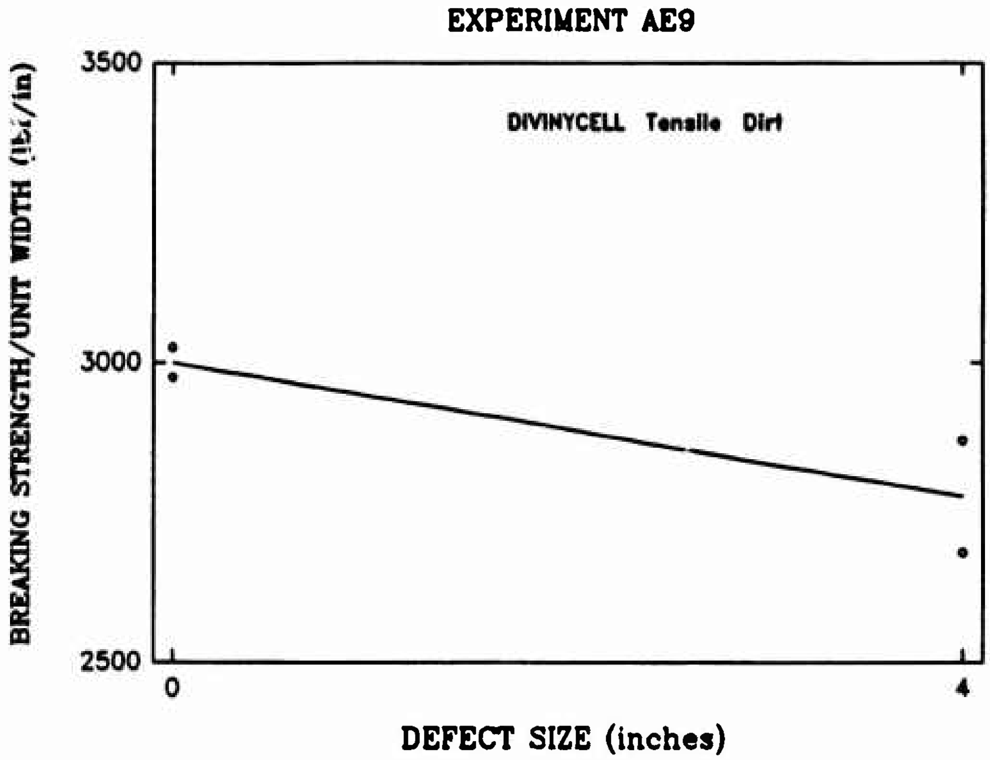


Figure C4-34

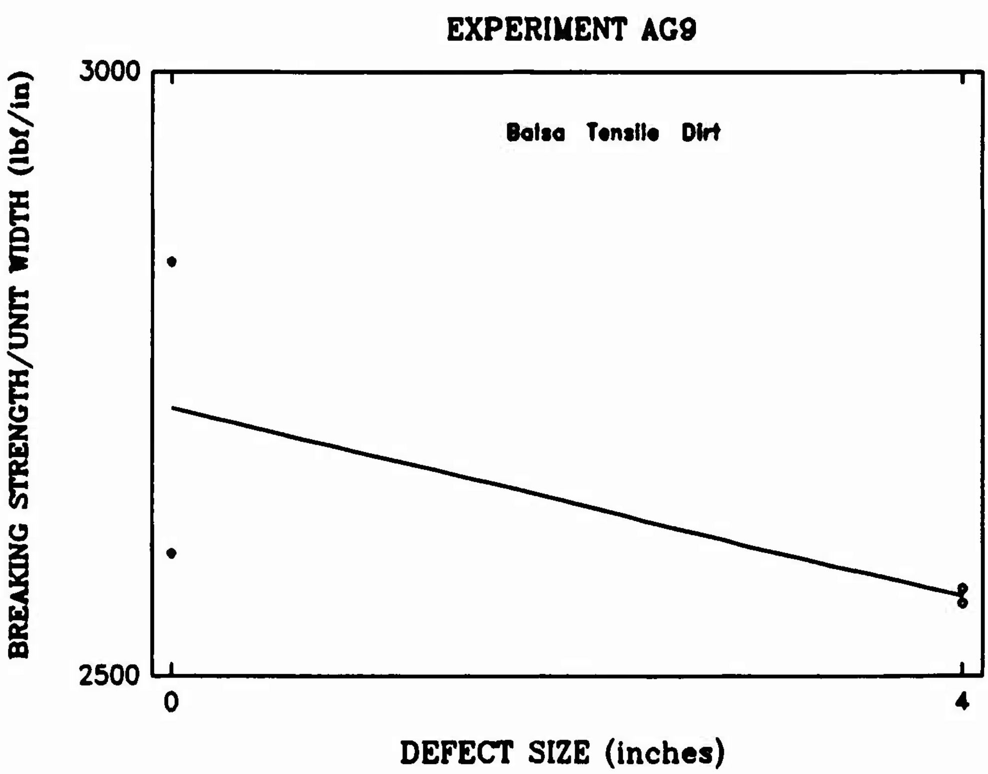


Figure C4-35

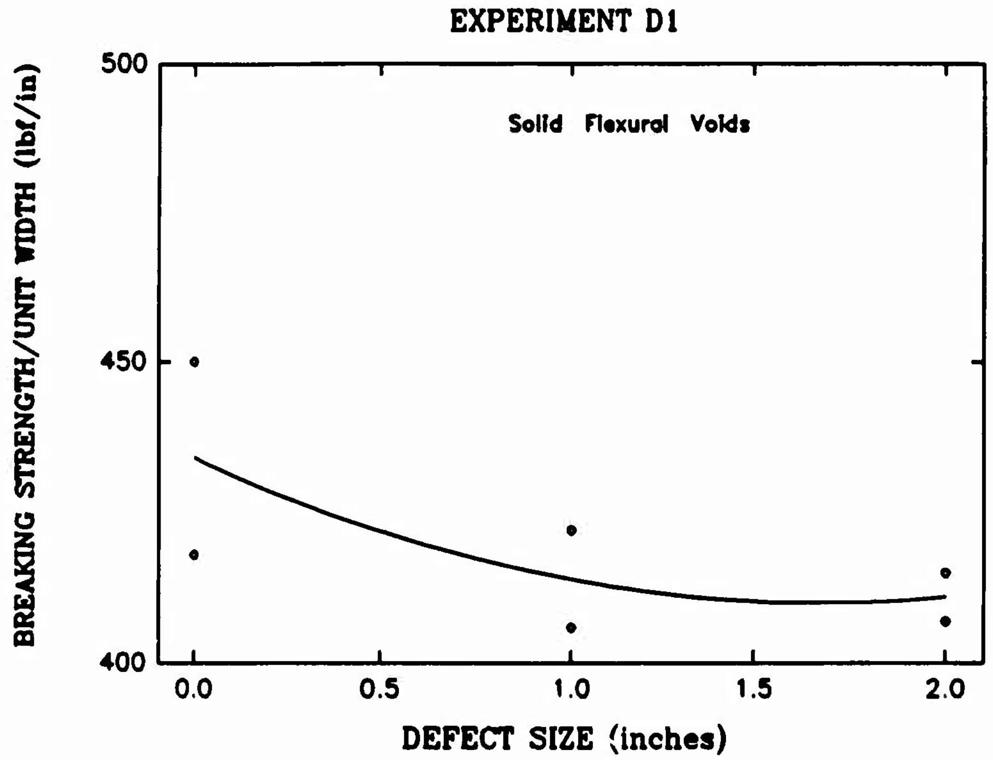


Figure C4-36

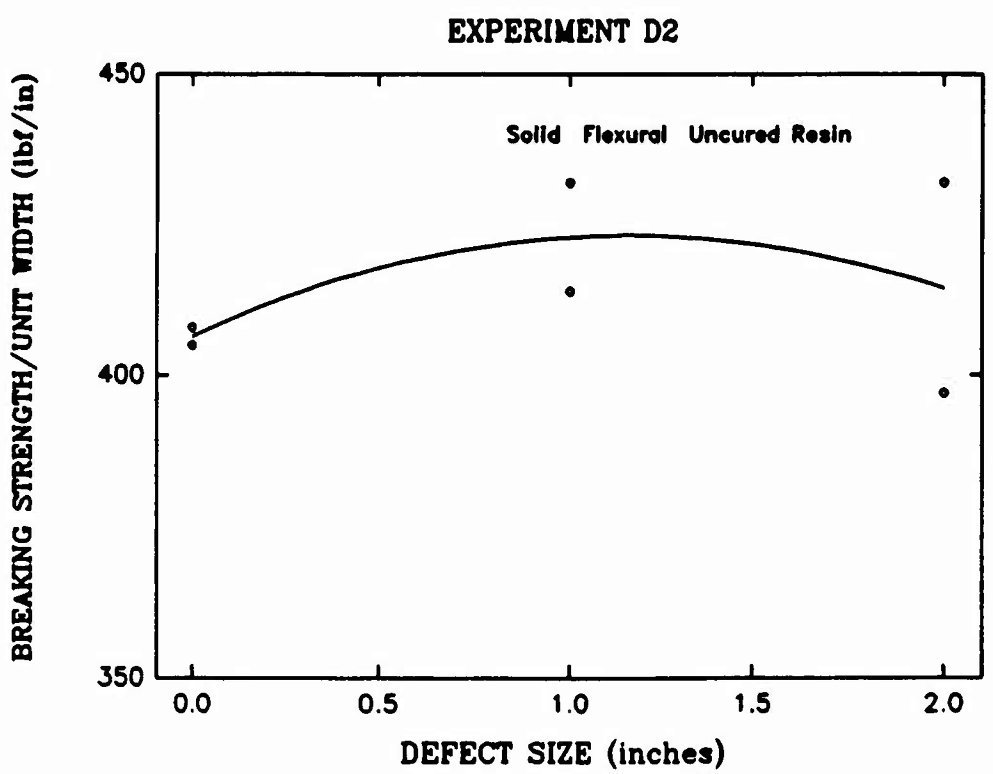


Figure C4-37

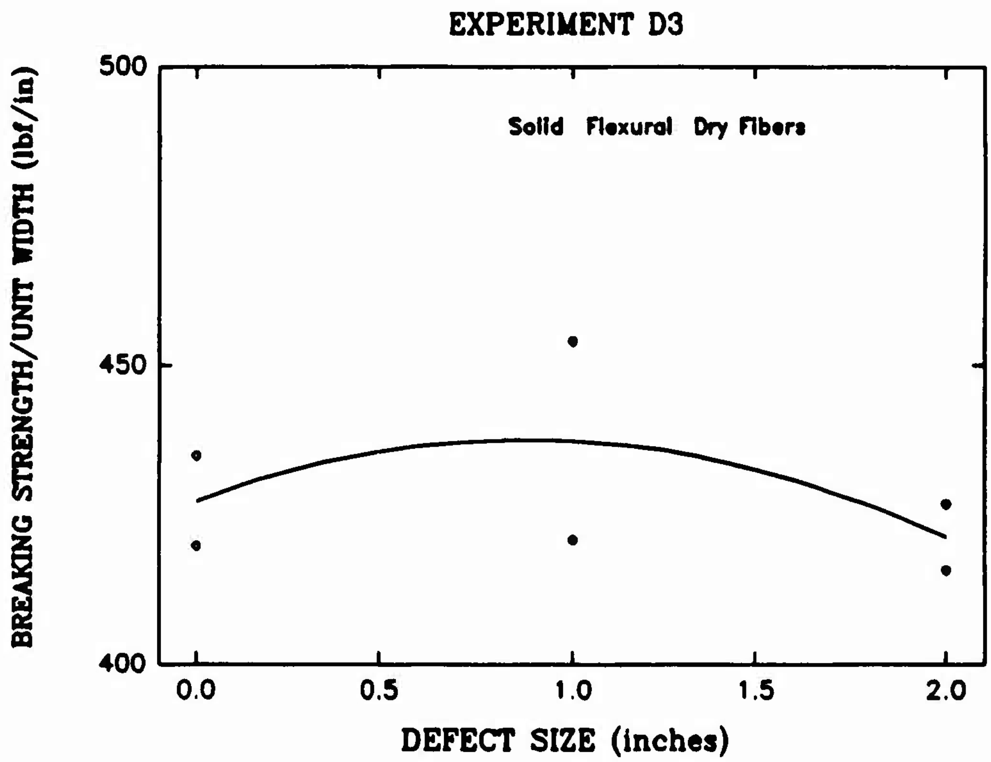


Figure C4-38

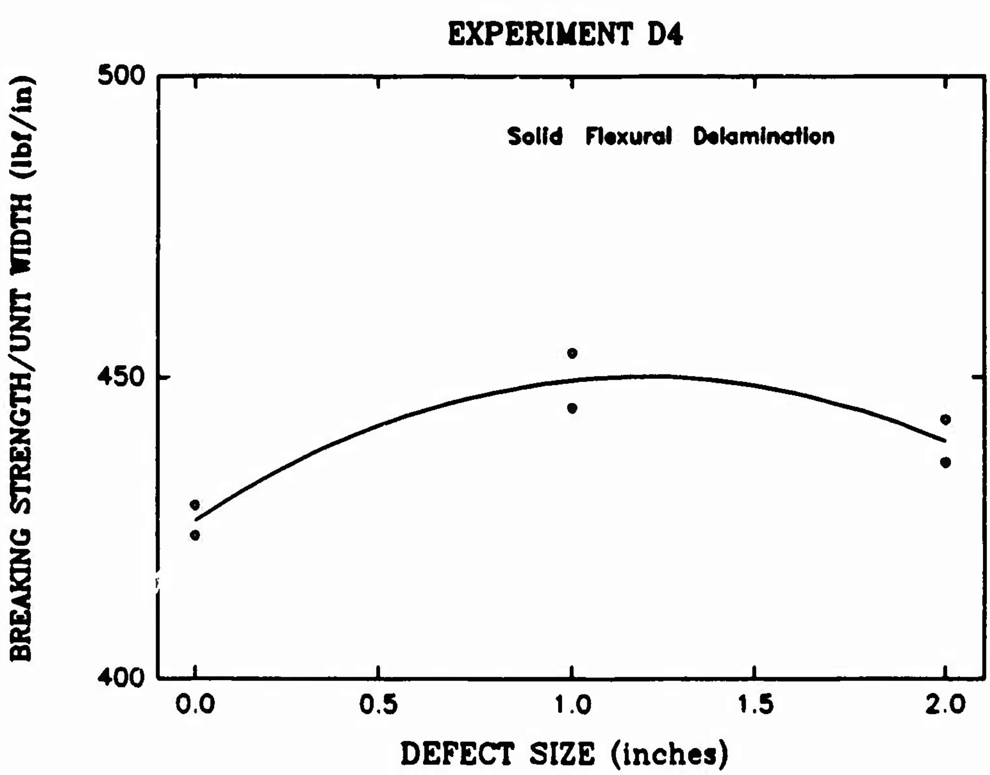


Figure C4-39

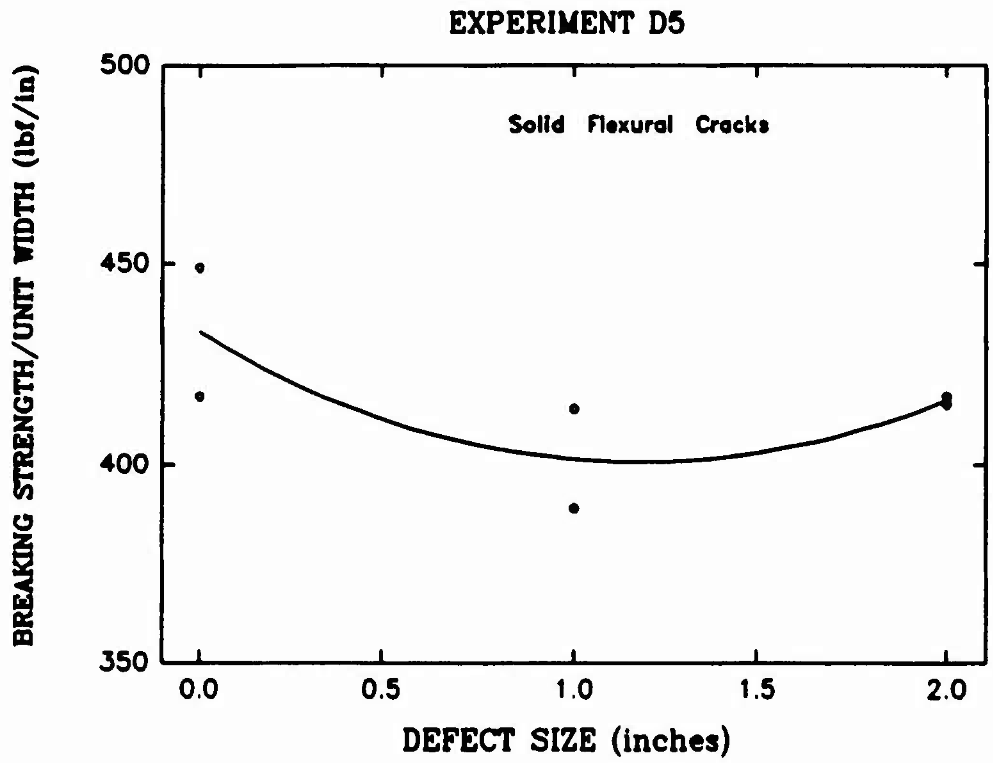


Figure C4-40

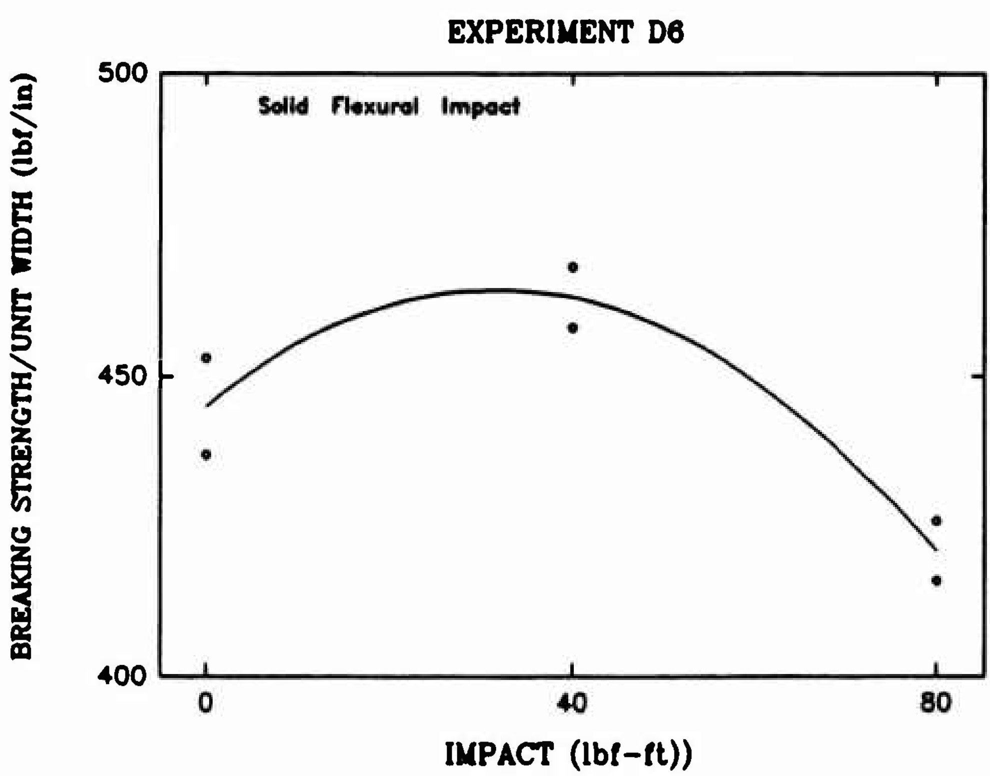


Figure C4-41

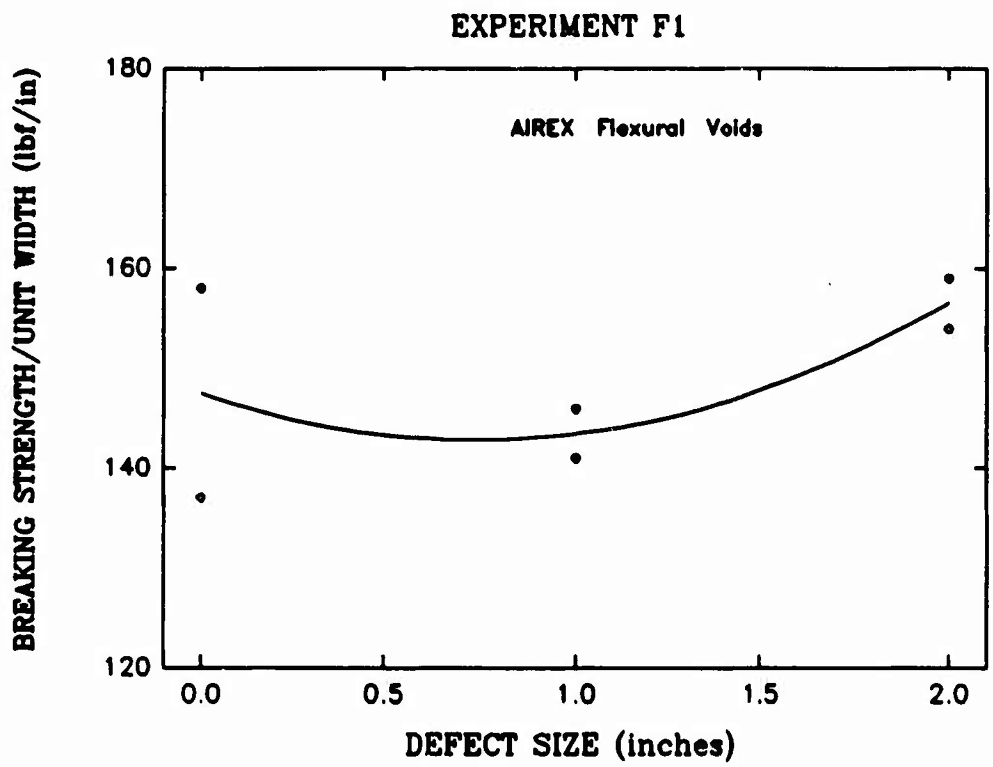


Figure C4-42

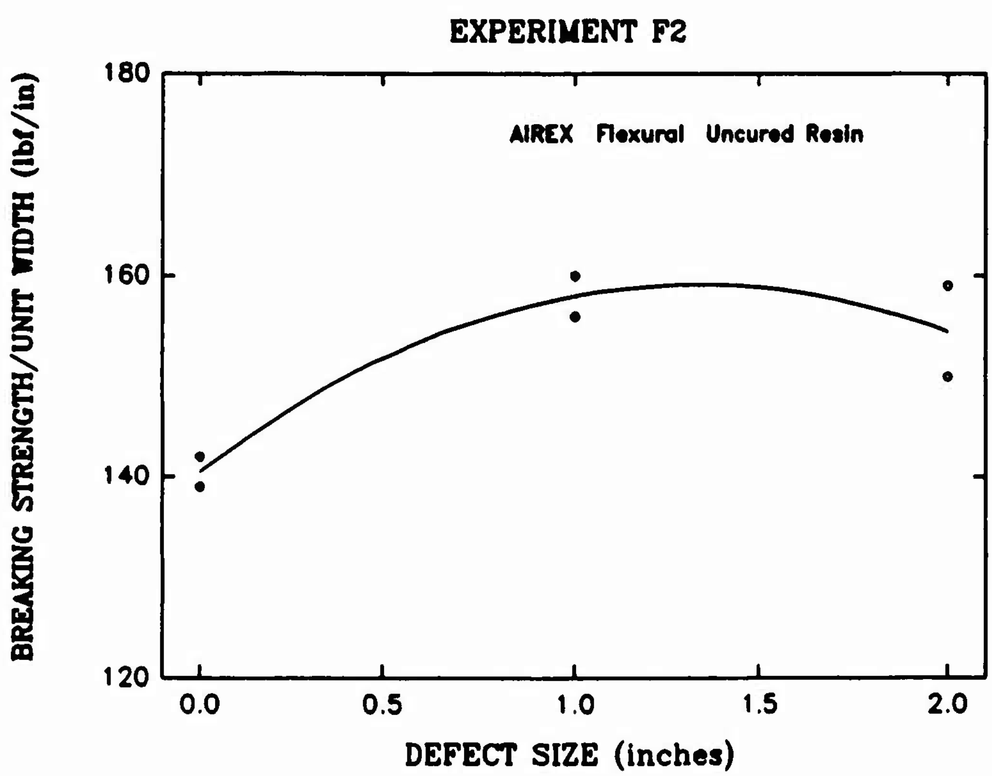


Figure C4-43

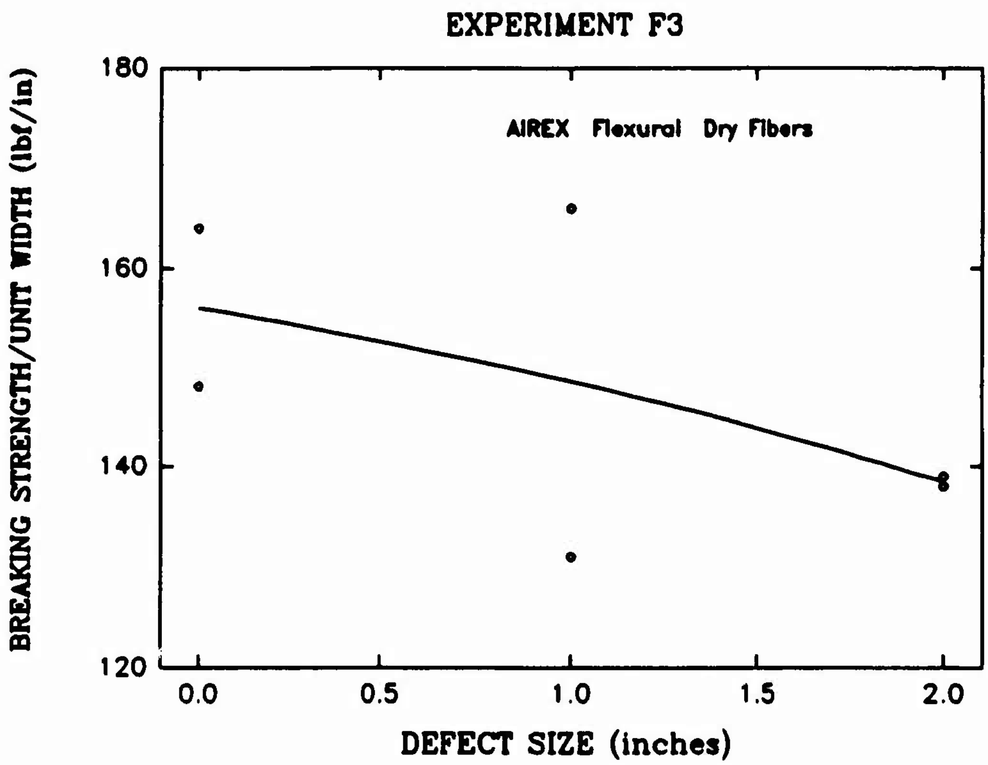


Figure C4-44

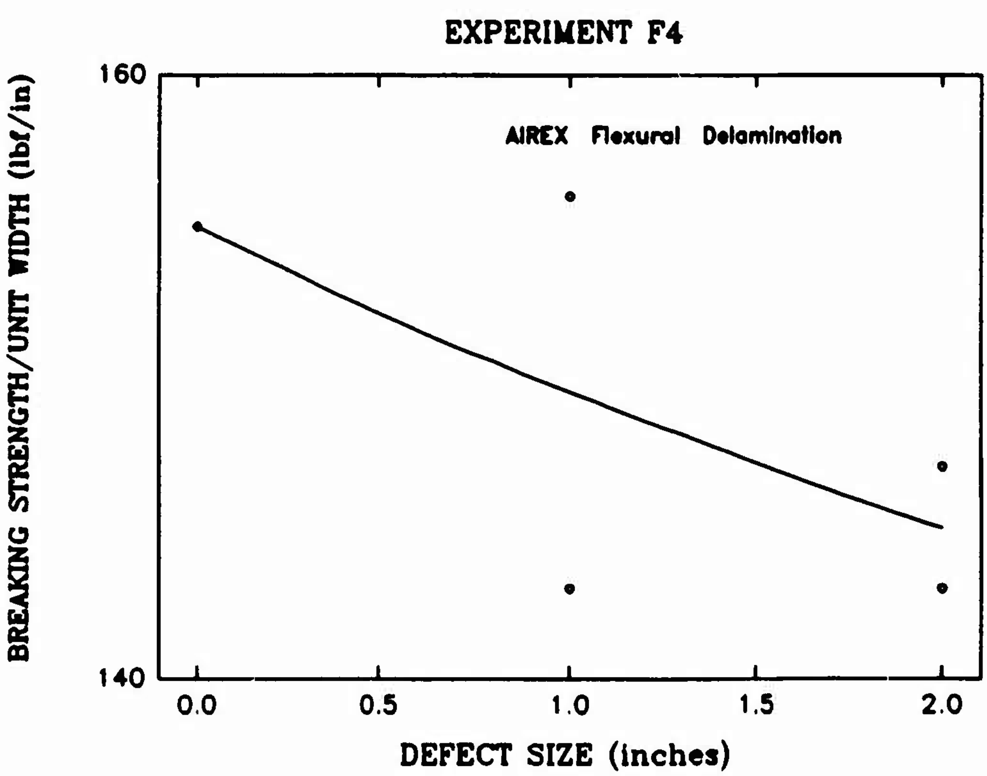


Figure C4-45

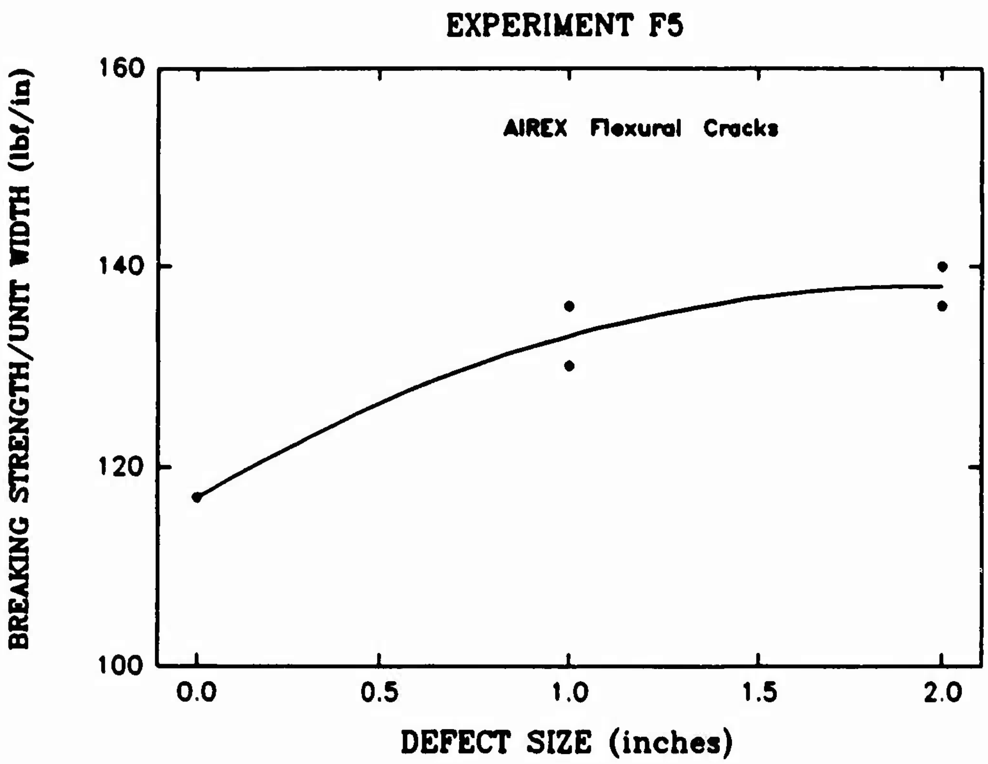


Figure C4-46

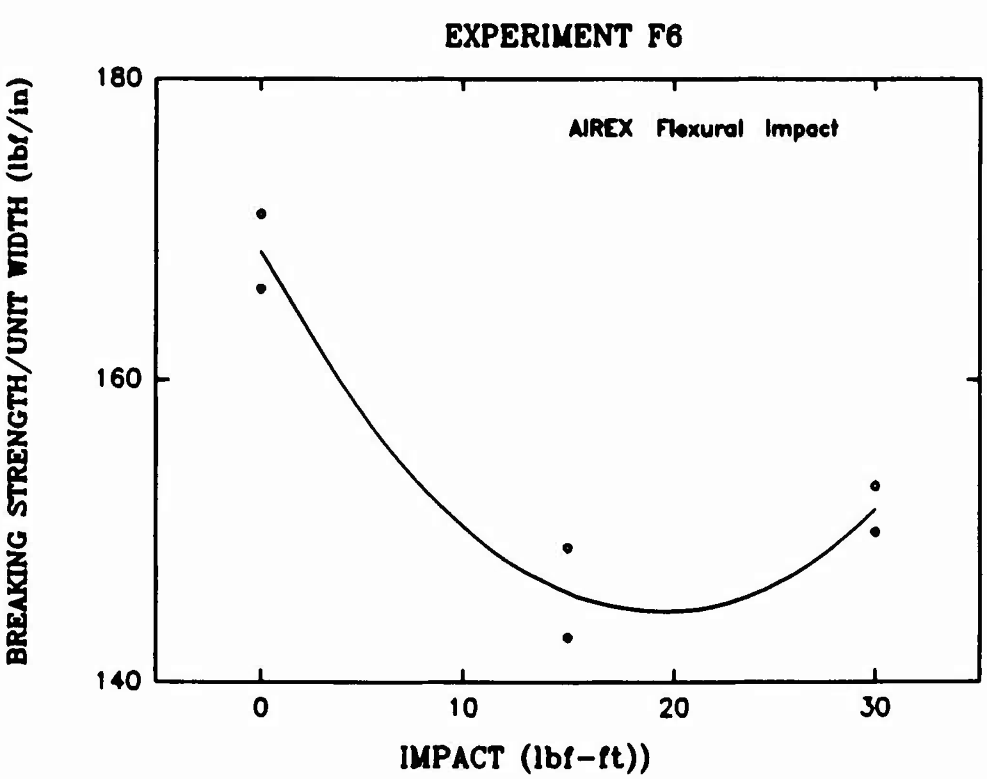


Figure C4-47

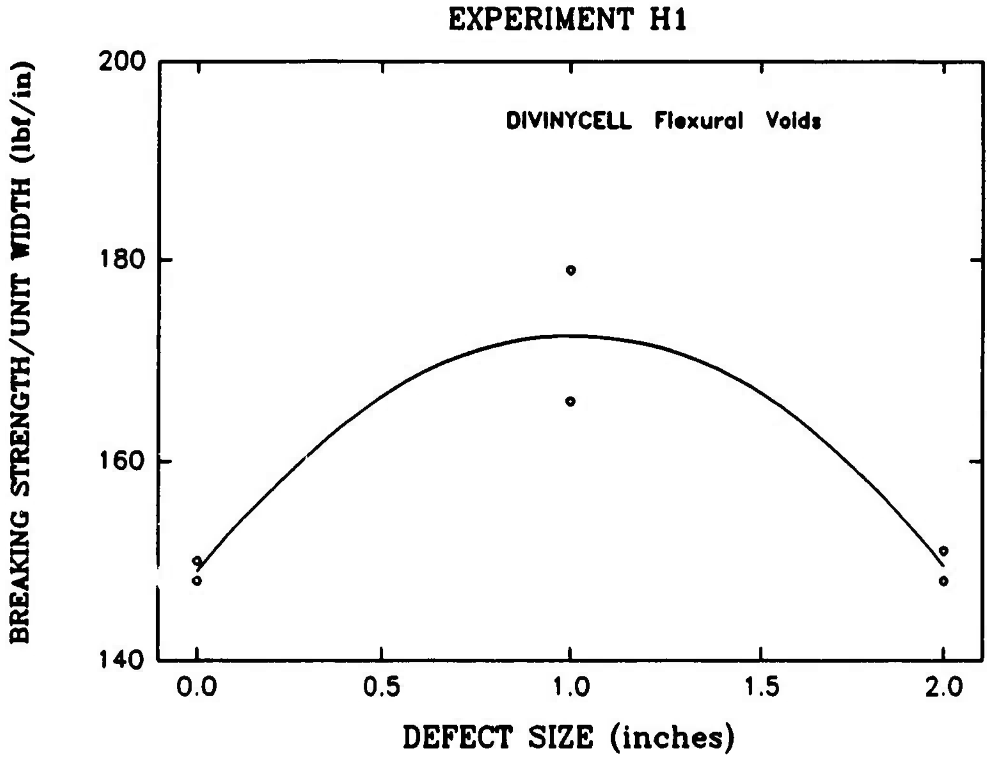


Figure **C4-48**

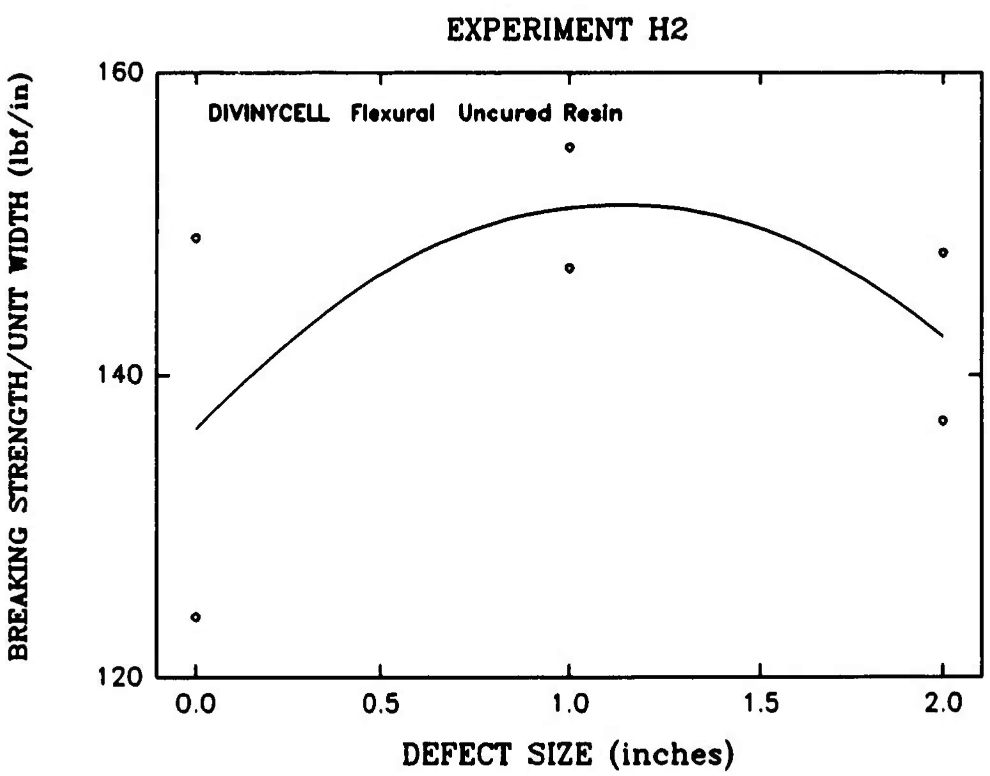


Figure **C4-49**

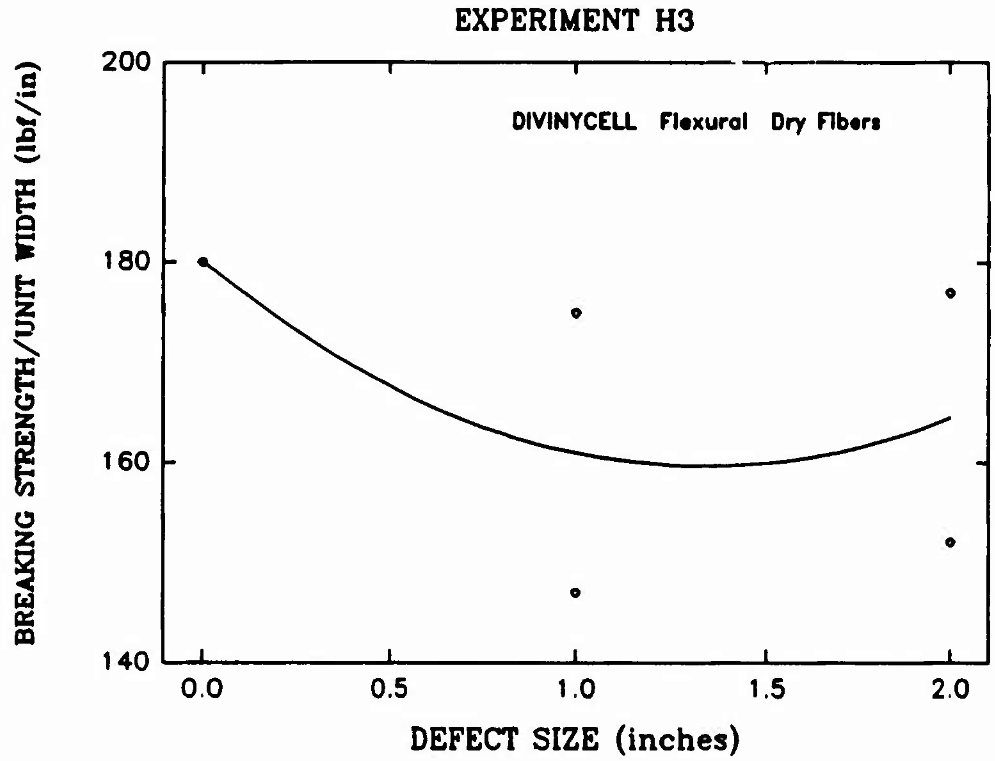


Figure C4-50

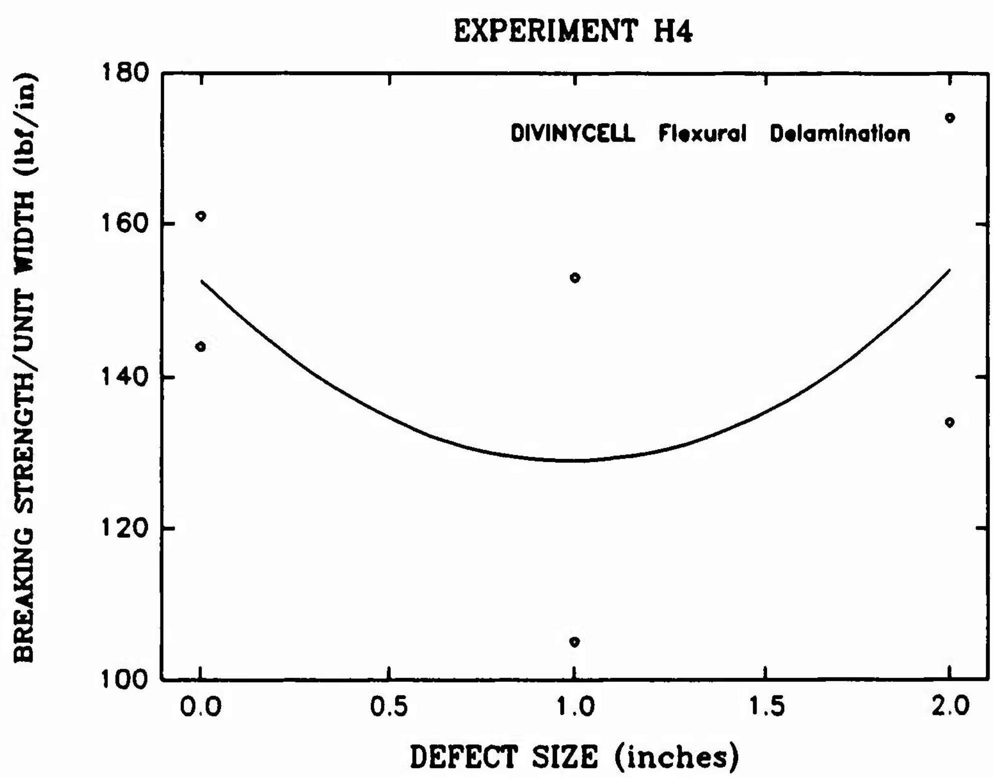


Figure C4-51

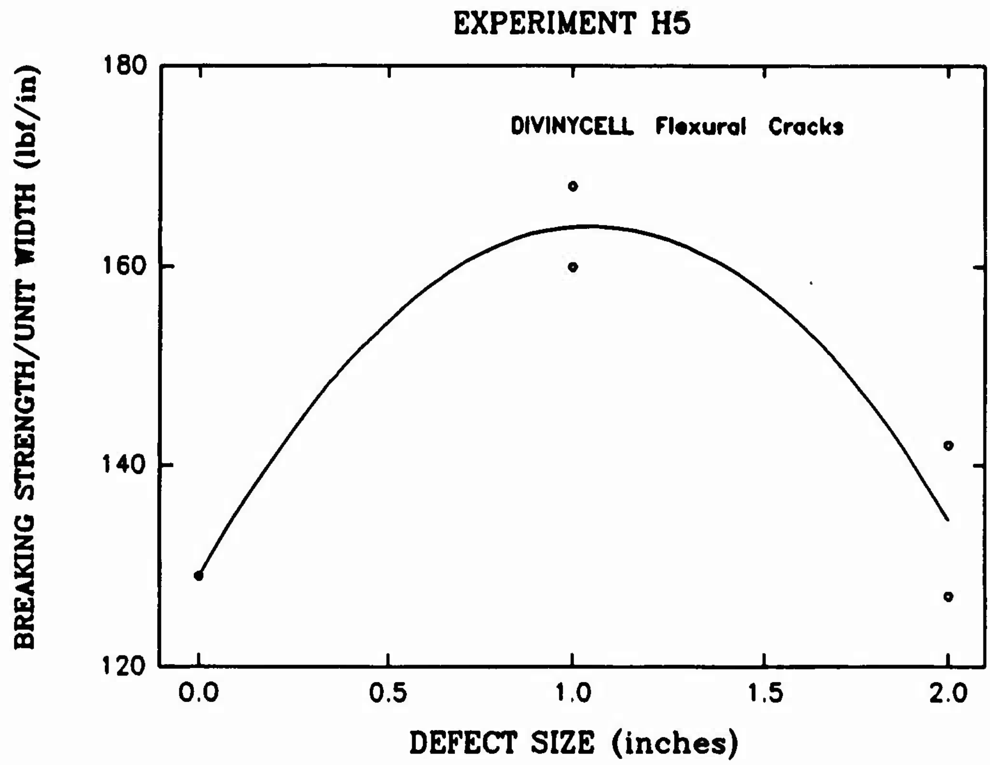


Figure C4-52

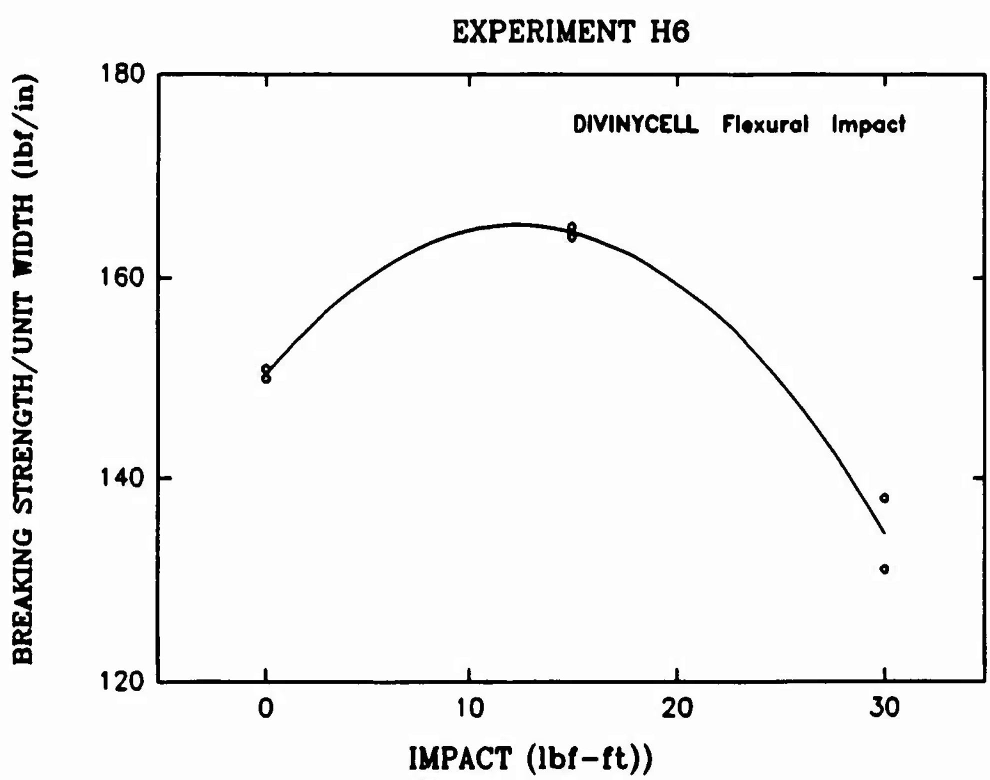


Figure C4-53

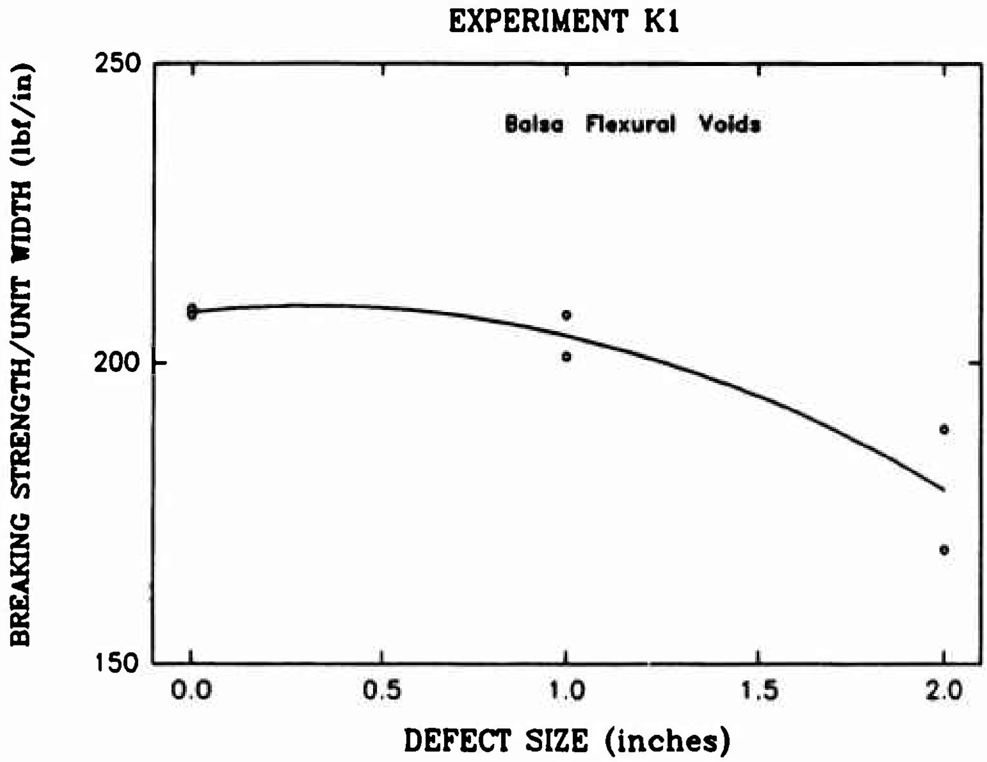


Figure C4-54

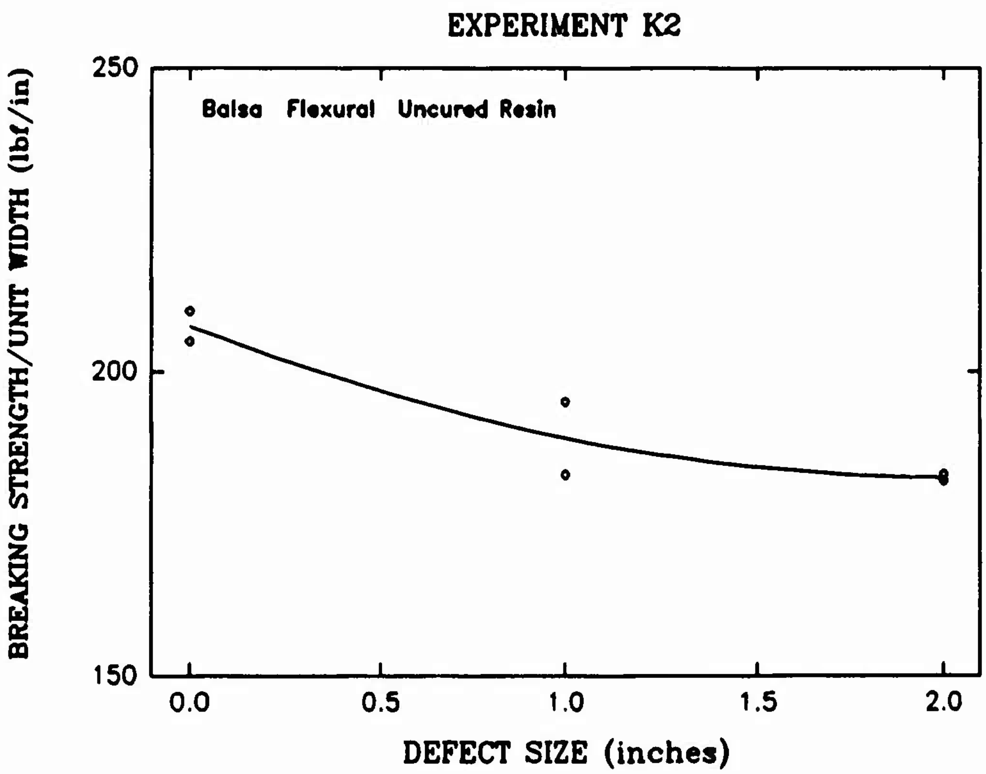


Figure C4-55

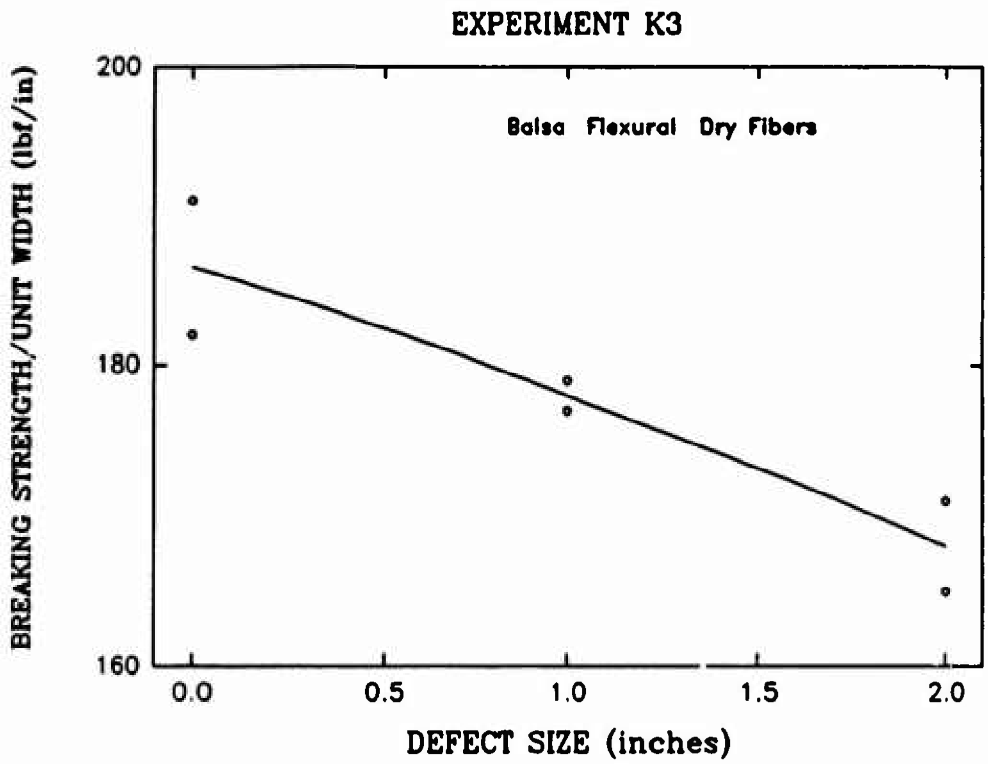


Figure C4-56

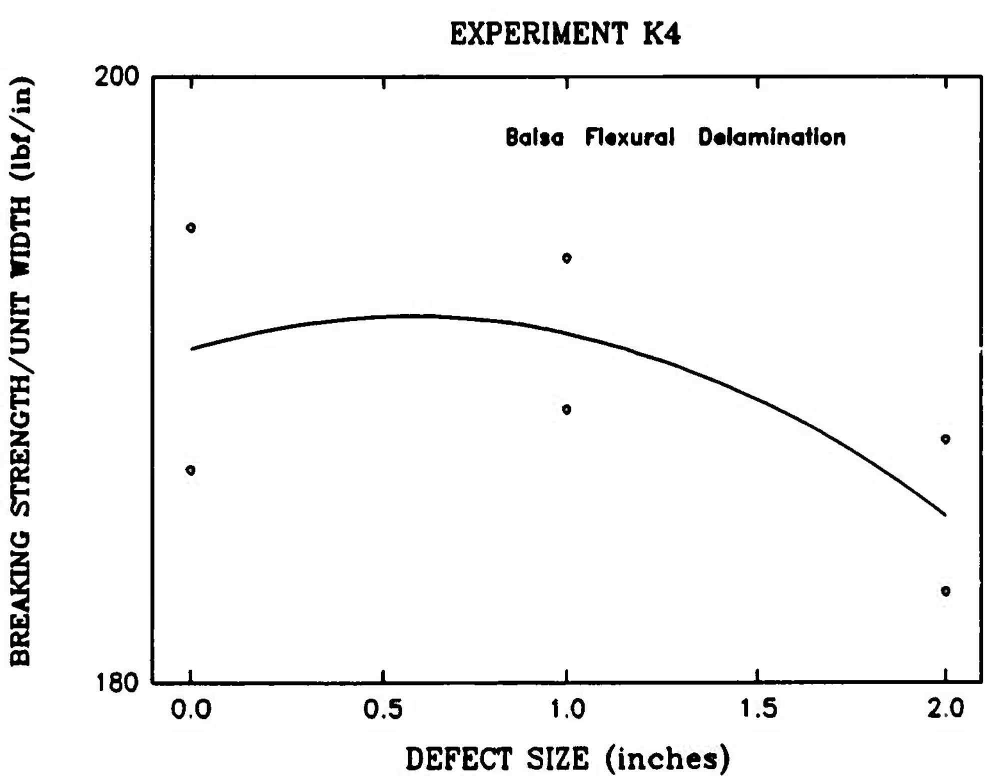


Figure C4-57

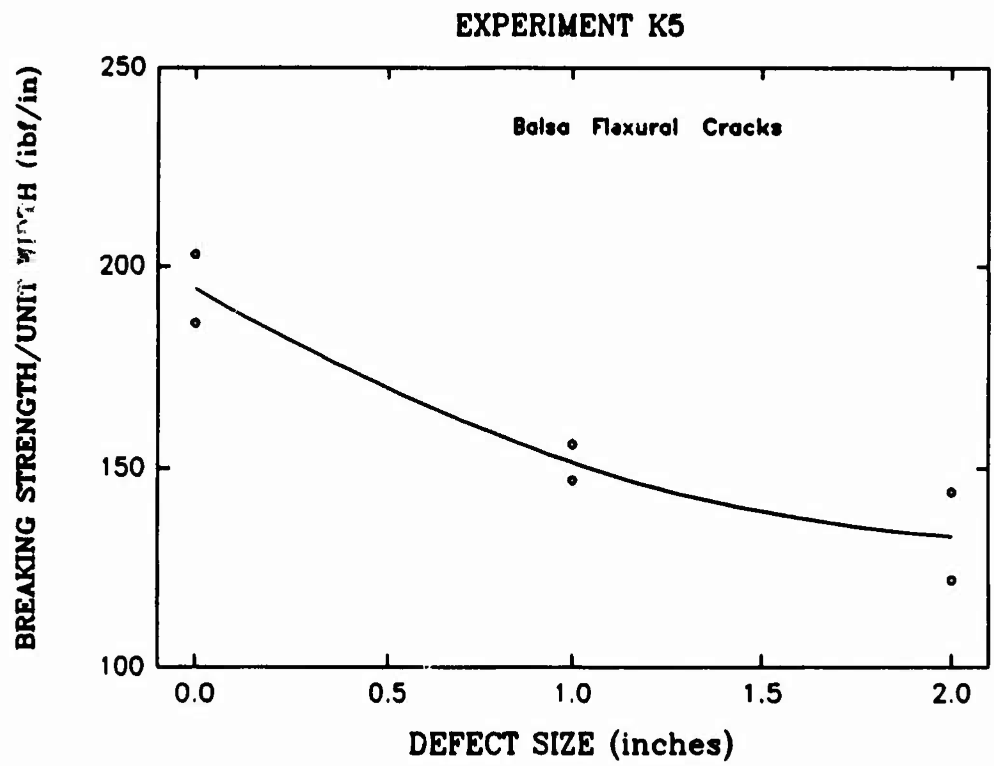


Figure C4-58

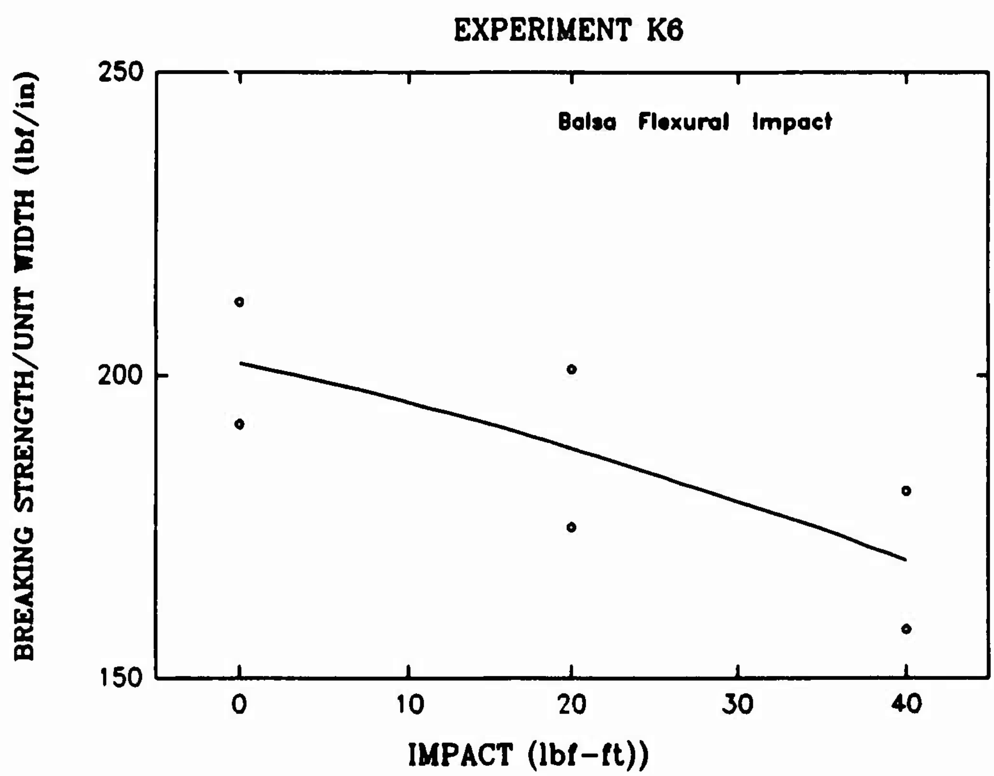


Figure C4-59

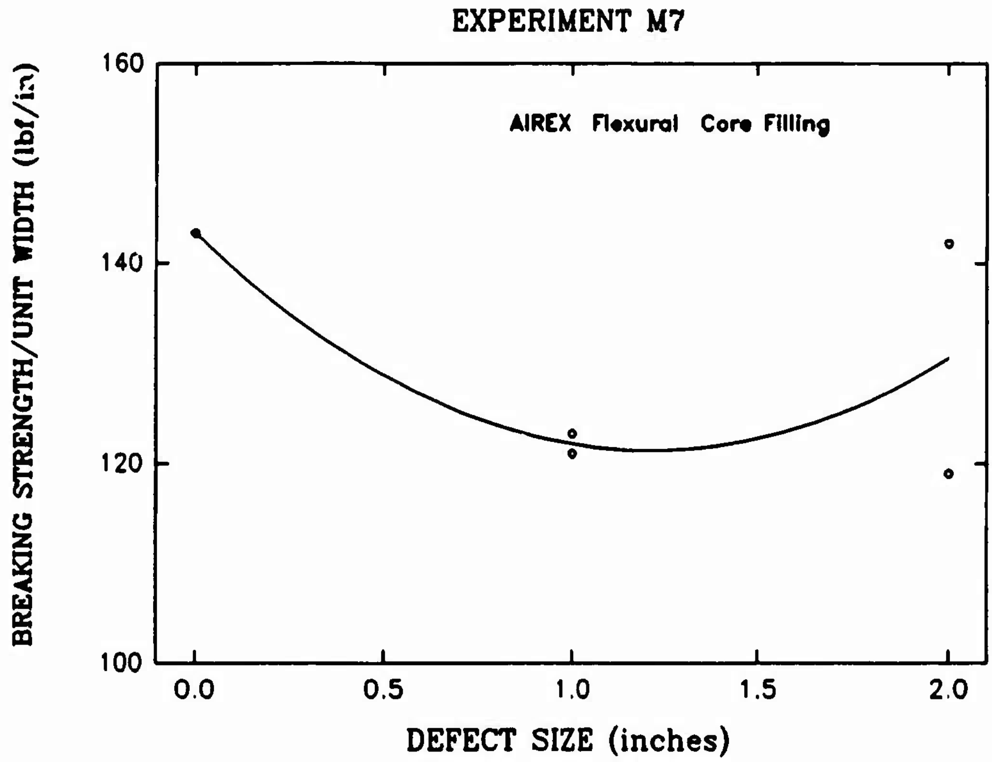


Figure **C4-60**

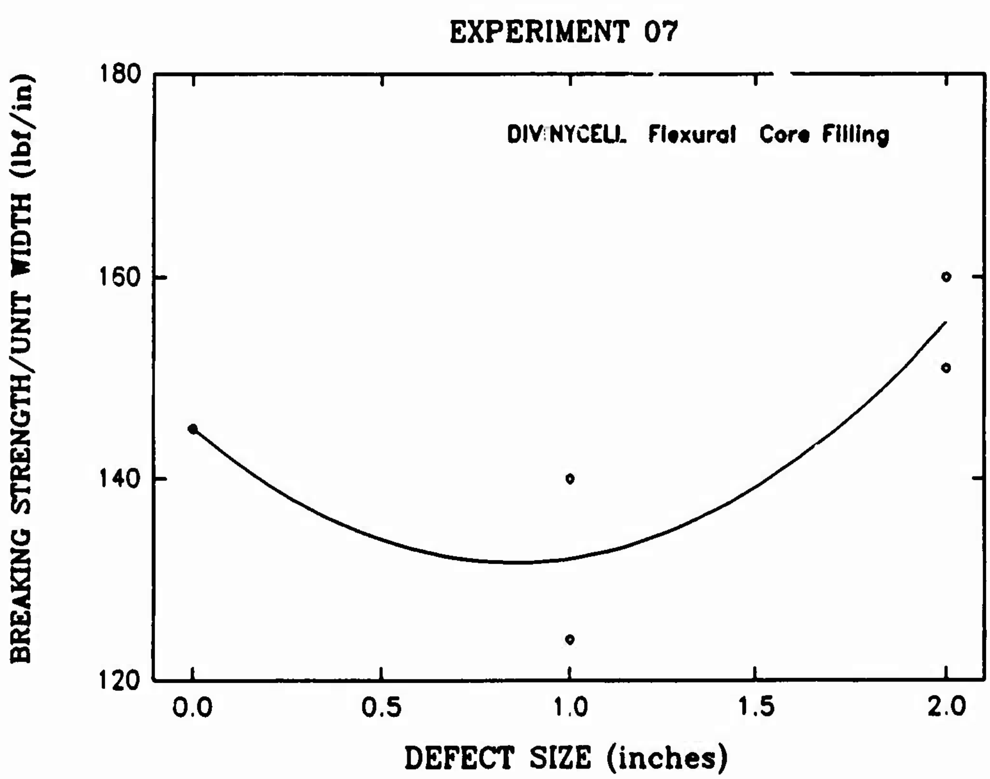
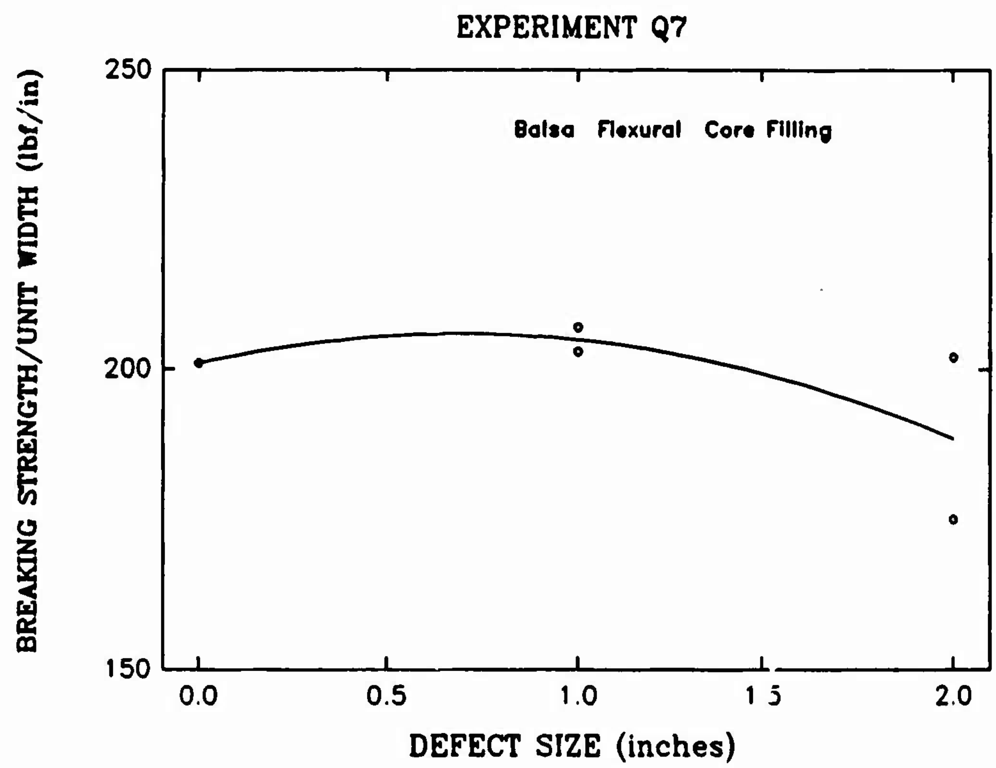


Figure **C4-61**



EXPERIMENT Q7
Balsa Flexural Core Filling
BREAKING STRENGTH/UNIT WIDTH (lbf/in)
250
200
150
0.0
0.5
1.0
1.5
2.0
DEFECT SIZE (inches)

Figure C4-62

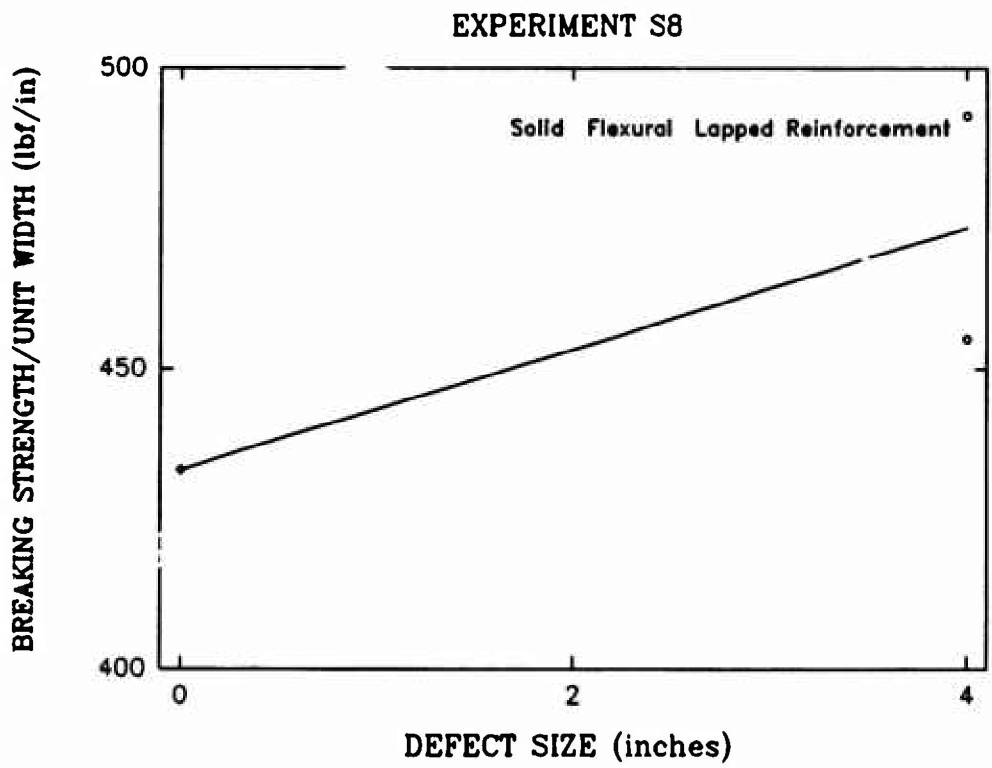


Figure C4-63

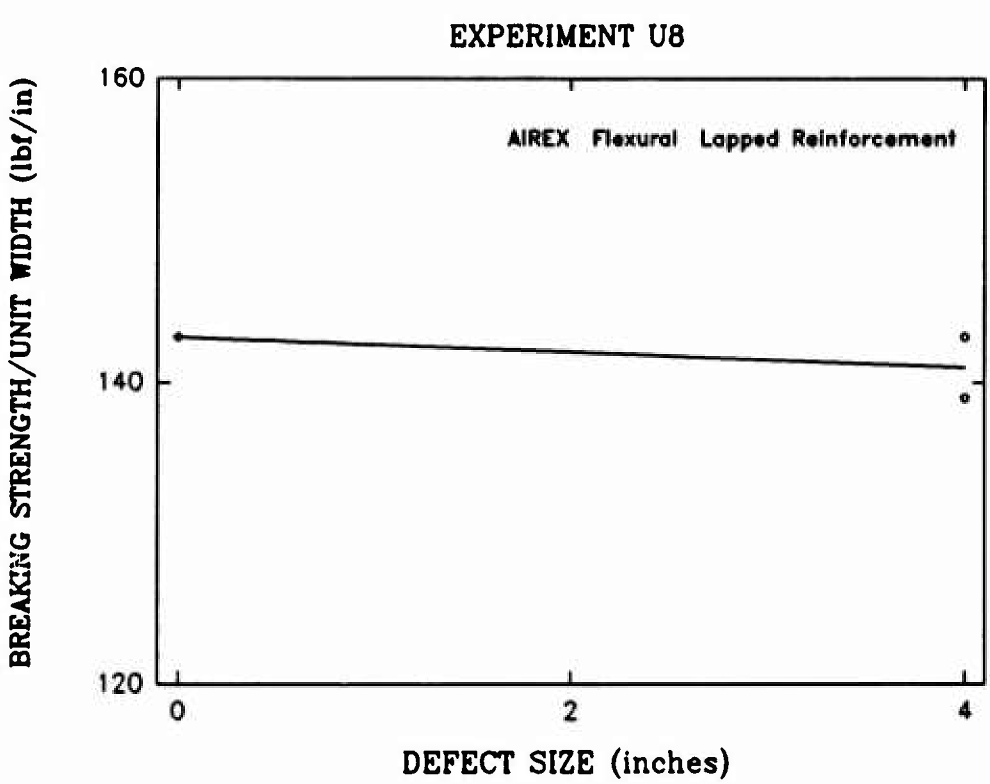


Figure C4-64

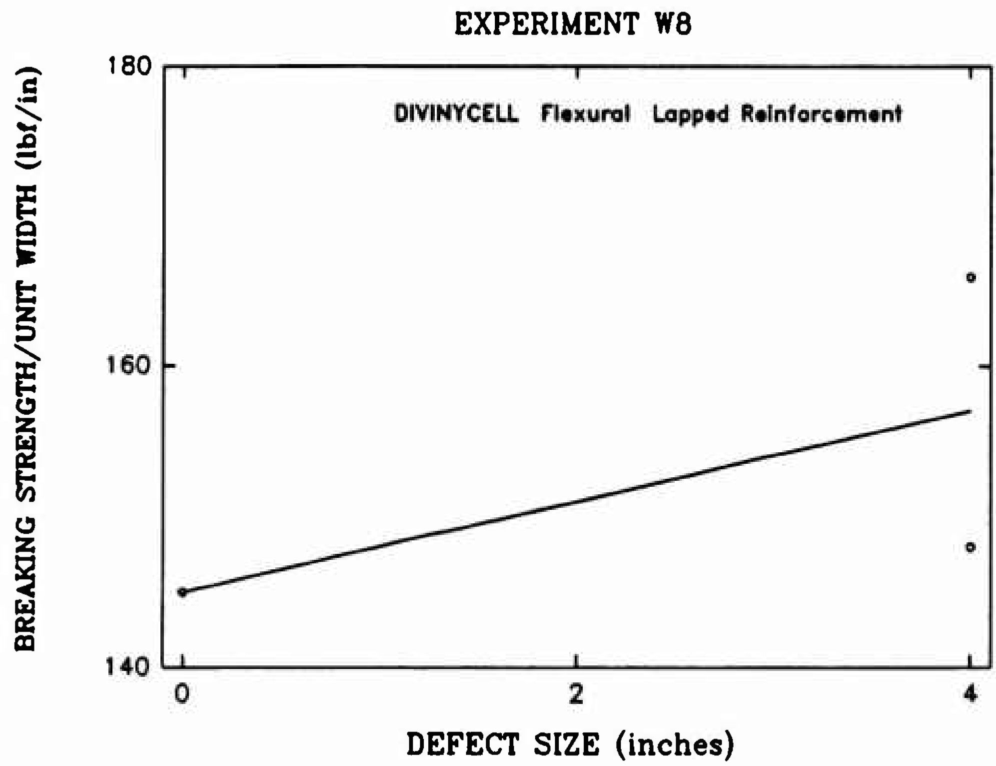


Figure **C4-65**

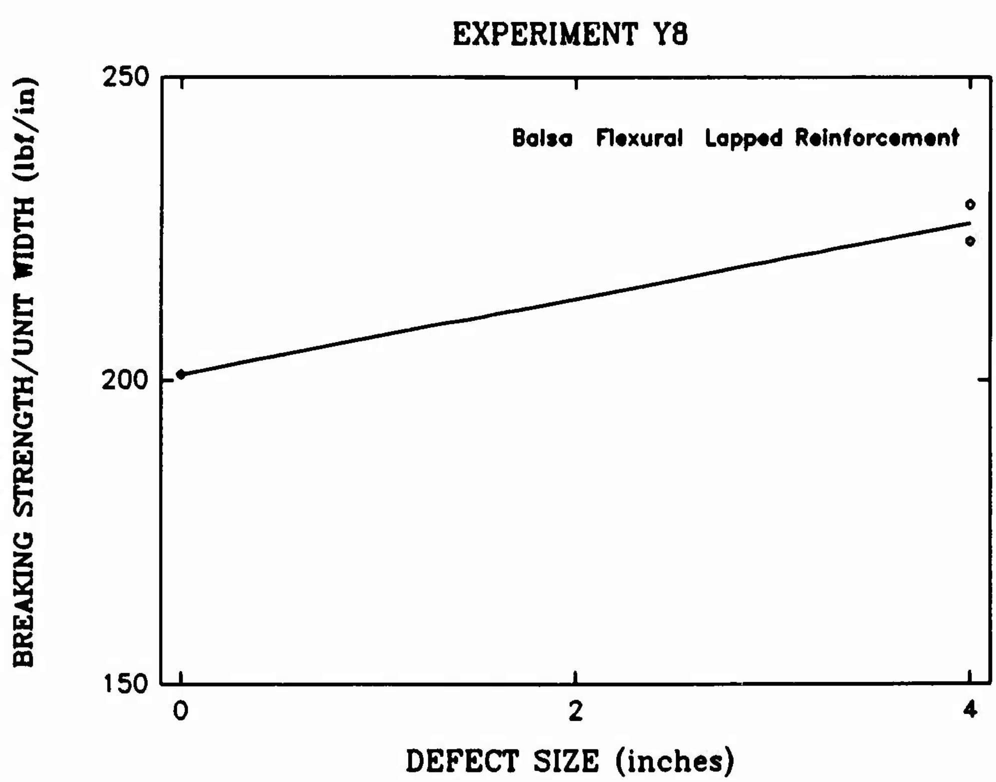


Figure **C4-66**

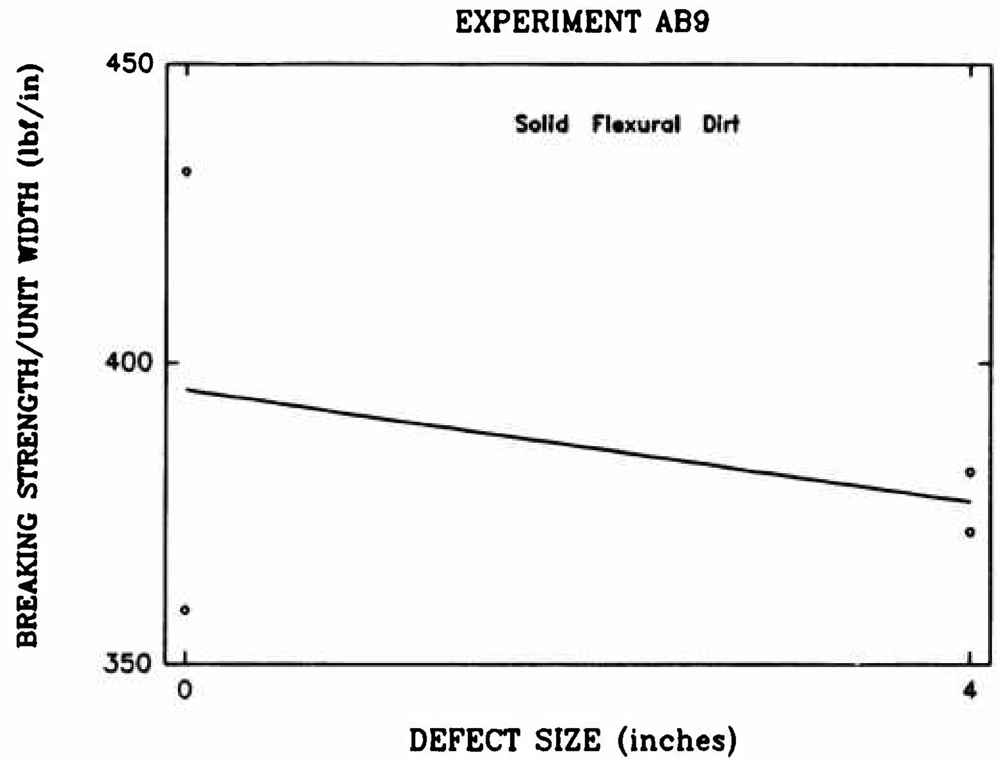


Figure C4-67

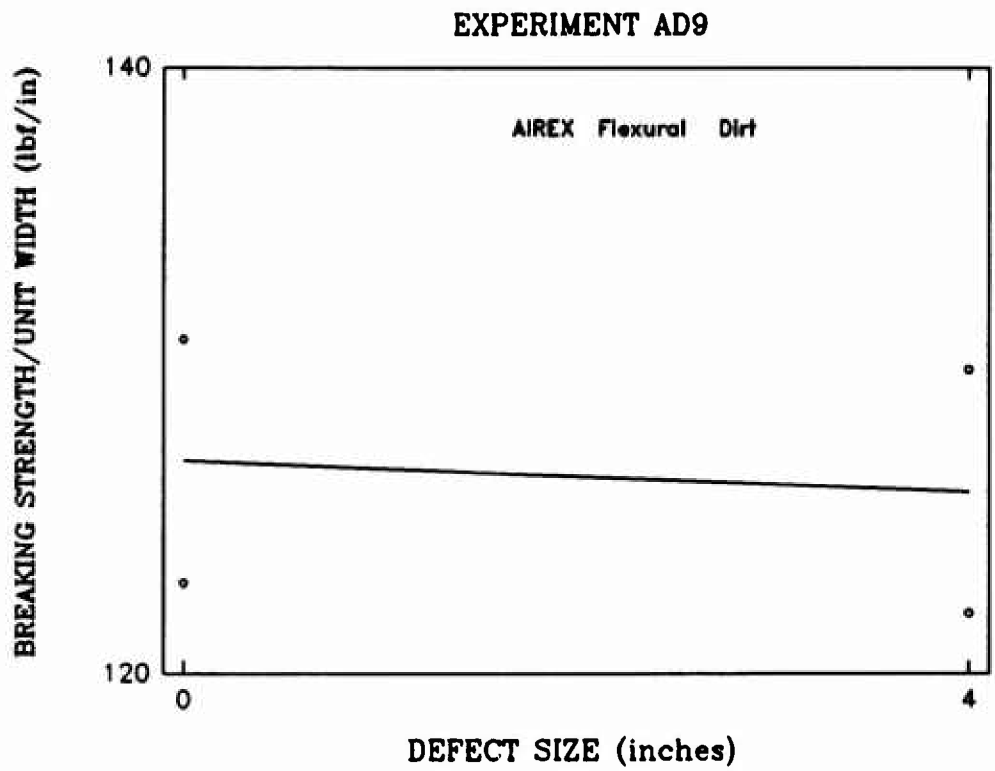


Figure C4-68

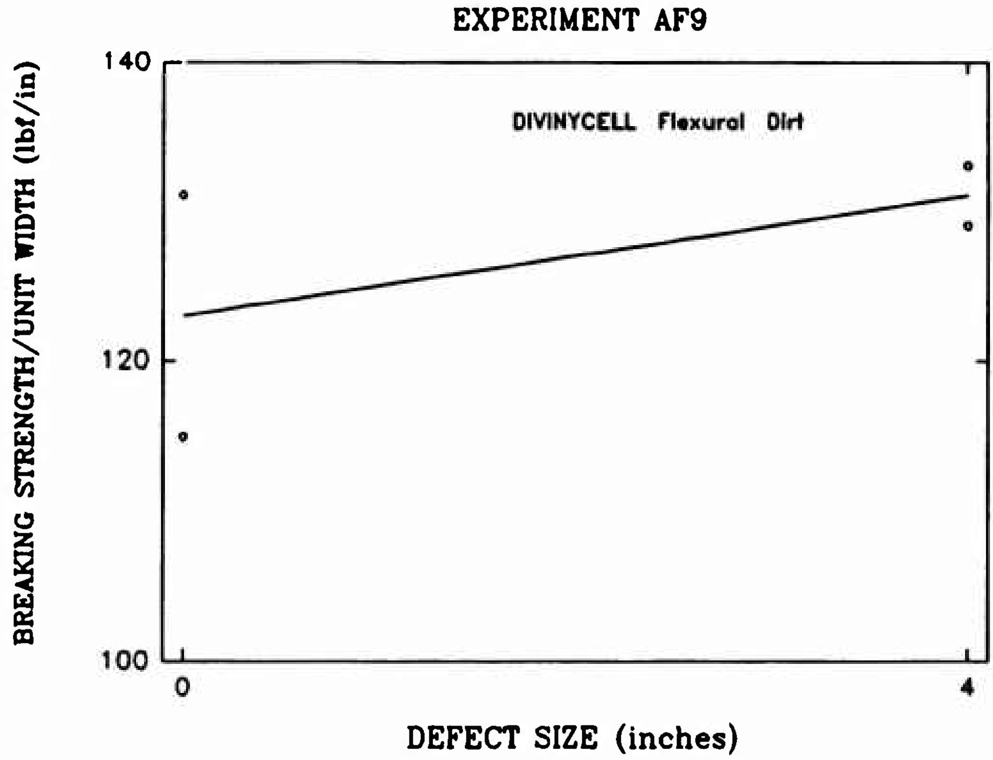


Figure **C4-69**

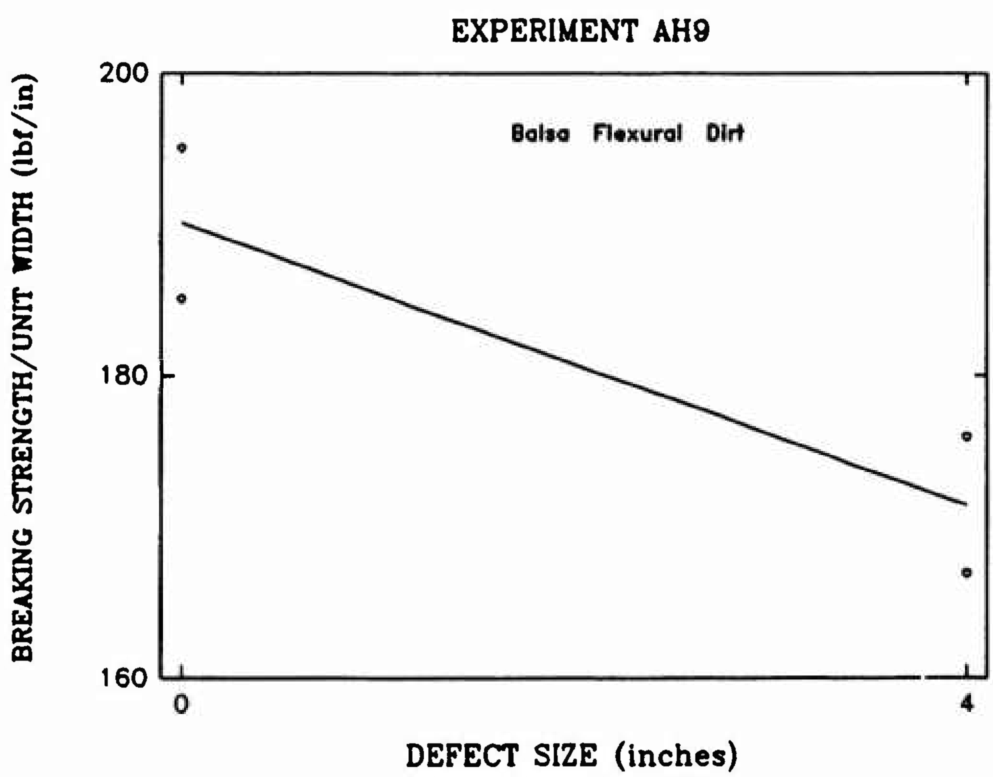


Figure **C4-70**

C5 Data Sheets - Unflawed Specimens

Solid Tensile Unflawed Specimens

8/19 Strength Report

Specnum	Core	Pmax	Strain	Dsize	Width	Strength
23/AA9-1-0	0.000	71862	18162	0.00	3.78	19028
23/AA9-2-0	0.000	68909	18036	0.00	3.77	18294
5/C1-1-0	0.000	72713	0	0.00	3.76	19320
5/C1-6-0	0.000	76416	0	0.00	3.77	20287
5/C2-1-0	0.000	74264	21772	0.00	3.76	19756
5/C2-6-0	0.000	69960	19326	0.00	3.77	18564
5/C3-1-0	0.000	75265	21309	0.00	3.77	19975
5/C3-6-0	0.000	71111	19425	0.00	3.76	18919
5/C4-1-0	0.000	76817	0	0.00	3.77	20388
5/C4-6-0	0.000	73914	21289	0.00	3.77	19621
6/C5-1-0	0.000	73864	19650	0.00	3.78	19525
6/C5-6-0	0.000	75415	17909	0.00	3.81	19804
6/C6-1-0	0.000	71812	0	0.00	3.83	18771
6/C6-6-0	0.000	67658	17574	0.00	3.82	17691

Average Strength	19282
Number of Specimens	14

Airex Cored Tensile Unflawed Specimens

8/19 Strength Report

Specnum	Core	Pmax	Strain	Dsize	Width	Strength
24/AC9-1-0	.470	10681	16879	0.00	3.76	2842
24/AC9-2-0	.470	10341	17941	0.00	3.71	2788
26/E5-1-0	.470	11061	16606	0.00	3.75	2946
26/E5-6-0	.470	10341	18548	0.00	3.75	2756
8/E1-1-0	.470	9841	15106	0.00	3.75	2624
8/E1-6-0	.470	10781	18984	0.00	3.76	2866
8/E2-1-0	.470	9781	18798	0.00	3.74	2612
8/E2-6-0	.470	10461	17433	0.00	3.76	2785
8/E3-1-0	.470	10401	17619	0.00	3.75	2776
8/E3-6-0	.470	10621	17774	0.00	3.75	2832
8/E4-1-0	.470	9501	17464	0.00	3.75	2532
8/E4-6-0	.470	10181	0	0.00	3.75	2712
9/E6-6-0	.470	10541	19764	0.00	3.86	2733

Average Strength 2754
Number of Specimens 13

Divinycell Cored Tensile Unflawed Specimens

8/19 Strength Report

Specnum	Core	Pmax	Strain	Dsize	Width	Strength
11/G1-1-0	.492	9721	0	0.00	3.76	2584
11/G1-6-0	.492	10661	17881	0.00	3.76	2833
11/G2-1-0	.492	9961	13783	0.00	3.75	2658
11/G2-6-0	.492	10781	16545	0.00	3.76	2866
11/G3-1-0	.492	10161	0	0.00	3.76	2702
11/G3-6-0	.492	8721	12751	0.00	3.75	2329
11/G4-1-0	.492	10441	18275	0.00	3.74	2790
11/G4-6-0	.492	11000	17243	0.00	3.76	2927
12/G6-1-0	.492	11841	17967	0.00	3.92	3024
12/G6-6-0	.492	11481	15841	0.00	3.91	2937
24/AE9-1-0	.492	11361	22056	0.00	3.76	3025
24/AE9-2-0	.492	11041	17774	0.00	3.71	2975
26/G5-1-0	.492	11041	19161	0.00	3.76	2939
26/G5-6-0	.492	8941	13892	0.00	3.74	2388

Average Strength 2784
Number of Specimens 14

Balsa Cored Tensile Unflawed Specimens

8/19 Strength Report

Specnum	Core	Pmax	Strain	Dsize	Width	Strength
15/J1-1-0	.477	10481	14823	0.00	3.75	2794
15/J1-6-0	.477	10381	14599	0.00	3.76	2762
15/J2-1-0	.477	10041	13378	0.00	3.75	2674
15/J2-6-0	.477	9641	13442	0.00	3.74	2576
15/J3-1-0	.477	9821	13474	0.00	3.74	2623
15/J3-6-0	.477	10181	15659	0.00	3.76	2711
15/J4-1-0	.477	9421	13956	0.00	3.75	2512
15/J4-6-0	.477	10361	15498	0.00	3.76	2759
16/J6-1-0	.477	11301	14523	0.00	3.92	2883
16/J6-6-0	.477	11461	12726	0.00	3.92	2927
24/AG9-1-0	.477	9781	0	0.00	3.76	2601
24/AG9-2-0	.477	10241	17304	0.00	3.60	2843
25/J5-1-0	.477	10641	0	0.00	3.75	2837
25/J5-6-0	.477	10101	16150	0.00	3.75	2692

Average Strength 2728
Number of Specimens 14

Solid Flexural Unflawed Specimens

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Core	Width	Strength
1/A1-1-0	990	3.70	0.00	0.00	2.26	437
1/A1-10-0	1343	4.70	0.00	0.00	3.11	432
1/A1-19-0	1726	4.20	0.00	0.00	3.81	453
19/S8-1	1760	4.20	0.00	0.00	3.87	455
19/S8-2	1910	3.70	0.00	0.00	3.88	492
2/A5-1-0	960	4.10	0.00	0.00	2.30	417
2/A5-10-0	1423	4.40	0.00	0.00	3.11	458
2/A5-19-0	1666	4.30	0.00	0.00	3.81	437
23/AB9-1-0	1351	4.50	0.00	0.00	3.76	359
23/AB9-2-0	1631	4.30	0.00	0.00	3.77	432
6/D5-1-0	1718	4.40	0.00	0.00	3.83	449
6/D5-6-0	1623	4.50	0.00	0.00	3.89	417
6/D6-1-0	1671	4.10	0.00	0.00	3.82	437
6/D6-6-0	1733	3.80	0.00	0.00	3.82	453
7/D1-1-0	1573	4.20	0.00	0.00	3.76	418
7/D1-6-0	1693	4.10	0.00	0.00	3.76	450
7/D2-1-0	1536	4.30	0.00	0.00	3.77	408
7/D2-6-0	1528	4.30	0.00	0.00	3.77	405
7/D3-1-0	1581	4.30	0.00	0.00	3.77	420
7/D3-6-0	1636	4.20	0.00	0.00	3.76	435
7/D4-1-0	1601	4.10	0.00	0.00	3.77	424
7/D4-6-0	1618	4.30	0.00	0.00	3.77	429

Average Strength 433

Number of Specimens 22

Airex Cored Flexural Unflawed Specimens

8/18 Strength Report

Specnum	Pmax	Defl	Dsize	Core	Width	Strength
10/F1-1-0	535	1.60	0.00	.47	3.89	137
10/F1-6-0	613	2.30	0.00	.47	3.89	158
10/F2-1-0	538	2.00	0.00	.47	3.87	139
10/F2-6-0	550	2.20	0.00	.47	3.87	142
10/F3-1-0	575	2.00	0.00	.47	3.89	148
10/F3-6-0	638	3.00	0.00	.47	3.88	164
10/F4-1-0	598	2.30	0.00	.47	3.87	155
10/F4-6-0	600	2.30	0.00	.47	3.88	155
20/U8-1	563	1.50	0.00	.47	3.94	143
20/U8-2	546	1.40	0.00	.47	3.94	139
24/AD9-1-0	465	1.60	0.00	.47	3.77	123
24/AD9-2-0	490	2.00	0.00	.47	3.75	131
26-F5-1-0	407	1.60	0.00	.47	3.76	108
26/F5-6-0	440	1.70	0.00	.47	3.76	117
3/B1-1-0	335	1.80	0.00	.47	2.27	147
3/B1-10-0	426	1.60	0.00	.47	3.07	139
3/B1-19-0	587	1.90	0.00	.47	3.86	152
4/B5-1-0	282	1.60	0.00	.47	2.25	125
4/B5-10-0	406	1.90	0.00	.47	3.07	132
4/B5-19-0	564	2.10	0.00	.47	3.92	144
9/F6-1-0	640	2.30	0.00	.47	3.86	166
9/F6-6-0	658	2.50	0.00	.47	3.85	171

Average Strength 143

Number of Specimens 22

Divinycell Cored Flexural Unflawed Specimens

8/19 Strength Report

Specnum	Pmax	Defl	Dsize	Core	Width	Strength
12/H6-1-0	590	1.60	0.00	.49	3.92	151
12/H6-6-0	589	1.60	0.00	.49	3.92	150
14/H1-1-0	588	1.50	0.00	.49	3.92	150
14/H1-6-0	571	1.50	0.00	.49	3.86	148
14/H2-1-0	480	1.40	0.00	.49	3.86	124
14/H2-6-0	574	1.70	0.00	.49	3.86	149
14/H3-1-0	696	1.90	0.00	.49	3.86	180
14/H4-1-0	620	1.70	0.00	.49	3.85	161
14/H4-6-0	557	1.70	0.00	.49	3.86	144
14/H6-6-0	552	1.40	0.00	.49	3.86	143
21/W8-1	652	1.60	0.00	.49	3.94	166
21/W8-2	583	1.30	0.00	.49	3.94	148
24/AF9-1-0	431	1.40	0.00	.49	3.75	115
24/AF9-2-0	481	1.60	0.00	.49	3.68	131
26/H5-1-0	485	1.90	0.00	.49	3.76	129
26/H5-6-0	486	1.70	0.00	.49	3.75	129

Average Strength 145

Number of Specimens 16

Balsa Cored Flexural Unflawed Specimens

8/19 Strength Report

Specnum	Pmax	Defl	Dsize	Core	Width	Strength
16/K6-1-0	753	2.60	0.00	.48	3.92	192
16/K6-6-0	830	3.00	0.00	.48	3.92	212
17/K1-1-0	811	3.10	0.00	.48	3.88	209
17/K1-6-0	805	2.70	0.00	.48	3.88	208
17/K2-1-0	830	3.10	0.00	.48	3.95	210
17/K2-6-0	808	3.00	0.00	.48	3.95	205
17/K3-1-0	705	2.50	0.00	.48	3.87	182
17/K3-6-0	740	2.70	0.00	.48	3.88	191
17/K4-1-0	756	2.70	0.00	.48	3.88	195
17/K4-6-0	726	2.40	0.00	.48	3.88	187
22/Y8-1	898	2.60	0.00	.48	3.92	229
22/Y8-2	873	2.50	0.00	.48	3.92	223
24/AH9-1-0	732	2.70	0.00	.48	3.76	195
24/AH9-2-0	696	2.70	0.00	.48	3.75	185
25/K5-1-0	696	2.40	0.00	.48	3.74	186
25/K5-6-0	768	2.80	0.00	.48	3.78	203

Average Strength 201

Number of Specimens 16